

March 1981

DISCOVER

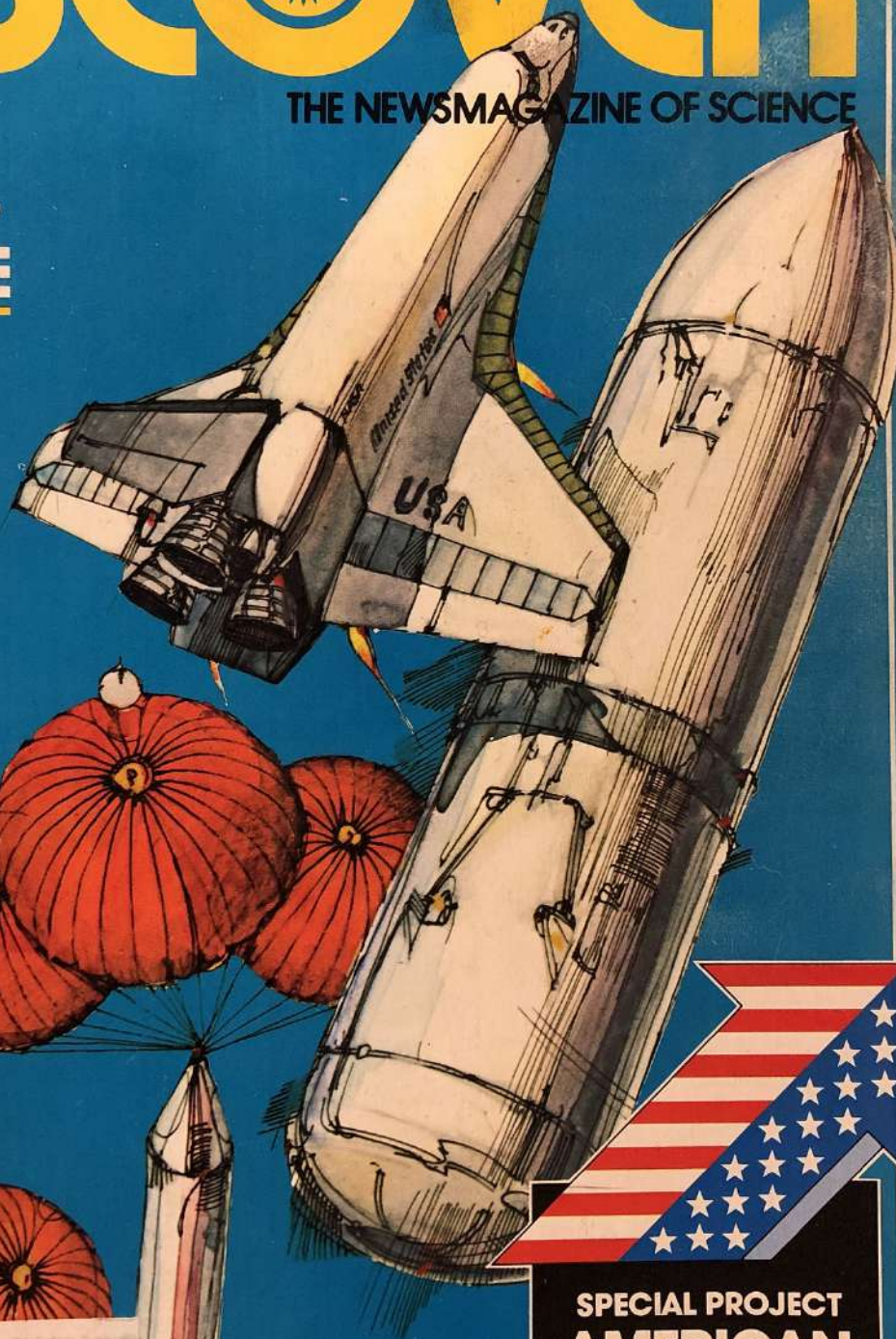
THE NEWSMAGAZINE OF SCIENCE

SHUTTLING INTO SPACE

HEALING
THE HOSTAGES

NEW LIGHT ON
BREAST EXAMS

PSYCHICS AND
THE PENTAGON



Shuttle separating
from fuel tank

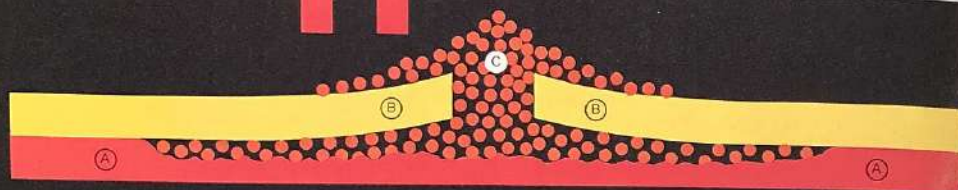
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**AMERICAN
RENEWAL**

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Consumer Orientation
No. 11 in a Series
Subject: Longlife Design.
The Antithesis of
Planned Obsolescence.

11

Porsche 911



At Porsche, we design our cars for the long term. We don't believe in the concept of planned obsolescence. Each new model is expected to have a production run of at least 10 years. (The 911 has been in production for more than 15 years.) In addition, every car we build is further expected to bring its owner many years of continued enjoyment.

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Paint alone is no protection against rust. (See diagram above.) Harmful elements can attack a car's sheet steel (A) through pinholes in the paint skin (B). Unchecked, rust (C) can expand, mar the finish, and weaken an ordinary steel body. So in addition to a 4-step paint process, the Porsche 911—like all Porsches—is protected by a hot dip galvanizing process.

All of the sheet steel used in all Porsches is hot dip galvanized—on both sides—in a 500°C liquid zinc bath. This pro-

duces (see diagram below) a protective zinc coating (D) on the sheet steel (E) that actually grows into the damaged portion (F) of the paint skin (G)—plugging pinholes and preventing further corrosion.

As a result of the effectiveness of hot dip galvanizing—beginning with the 1981 model year, we offer a limited warranty on the entire body of every new Porsche—911, 924, 924 Turbo, 928—against rust perforation for 7 years.

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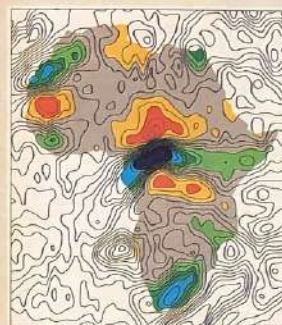


At the Porsche Research and Development Center (Entwicklungszentrum) in Weissach, the steel body of a Porsche 911 has been standing outside in the elements—protected only by hot dip galvanizing—for 7 years. To date, there has not been one speck of red rust.

MARCH / 1981

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THE NEWSMAGAZINE OF SCIENCE

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3. It makes the sounds that soothe.

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5 & 6. Amazing, what Realtime gives you for \$2,000 less than a Rolex.

Its quartz movement delivers ± 5 second-a-month accuracy—exceeding Swiss Chronometer standards. Its electronic circuitry never needs cleaning or repair. And its stylized bezel, supple link bracelet and magnifying date window bring to mind the peerless quality that makes Rolex watches so renowned—and so expensive.

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How often have you gone rushing from store to store, only to find exactly what you were looking for at Sears?

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The 46 Sears TV models are available in most larger Sears stores.



IS THERE A LASER GAP?

Can the superpowers produce laser weapons that will break the strategic deadlock?

by MONTE DAVIS

For more than 15 years the nuclear balance of terror—the certainty that neither superpower could escape devastation by the other's ballistic missiles—has dominated military strategy. But fast-improving laser technology may change that. Laser weaponry has already been tested on the ground and from aircraft in the United States, and probably in the Soviet Union, too. Now the prospect of laser-armed satellites, firing high-energy beams across thousands of miles to shoot down missiles soon after they were launched, has raised the possibility of an effective defense against a nuclear strike.

That would seem to be a welcome development. But it has not been received with undiluted joy in Washington, D.C., where a battle is shaping up over the military use of lasers. Opponents say that laser satellites are impractical and that they will be vulnerable to far

less expensive countermeasures. Even worse, they fear that an attempt to build them could upset the nuclear balance of terror—with unpredictable consequences. Advocates of lasers disagree, arguing that the Soviet Union is spending huge amounts to develop laser weapons and that the United States has no choice but to do the same.

Before leaving office, the Carter administration proposed a budget for fiscal 1982 (which starts October 1) that included \$261.3 million for military laser research. President Reagan may seek to increase that figure, and Caspar Weinberger, the new Secretary of Defense, hinted strongly that the administration would push for an advanced defense against ballistic missiles. But laser opponents took heart a few weeks before the change in administration when an MIT defense-technology study raised doubts that orbital laser weapons

could ever stop a missile attack.

The controversy over the laser-armed satellite boils down to two related questions: Will it be technically effective? And should the United States make a massive effort to deploy it?

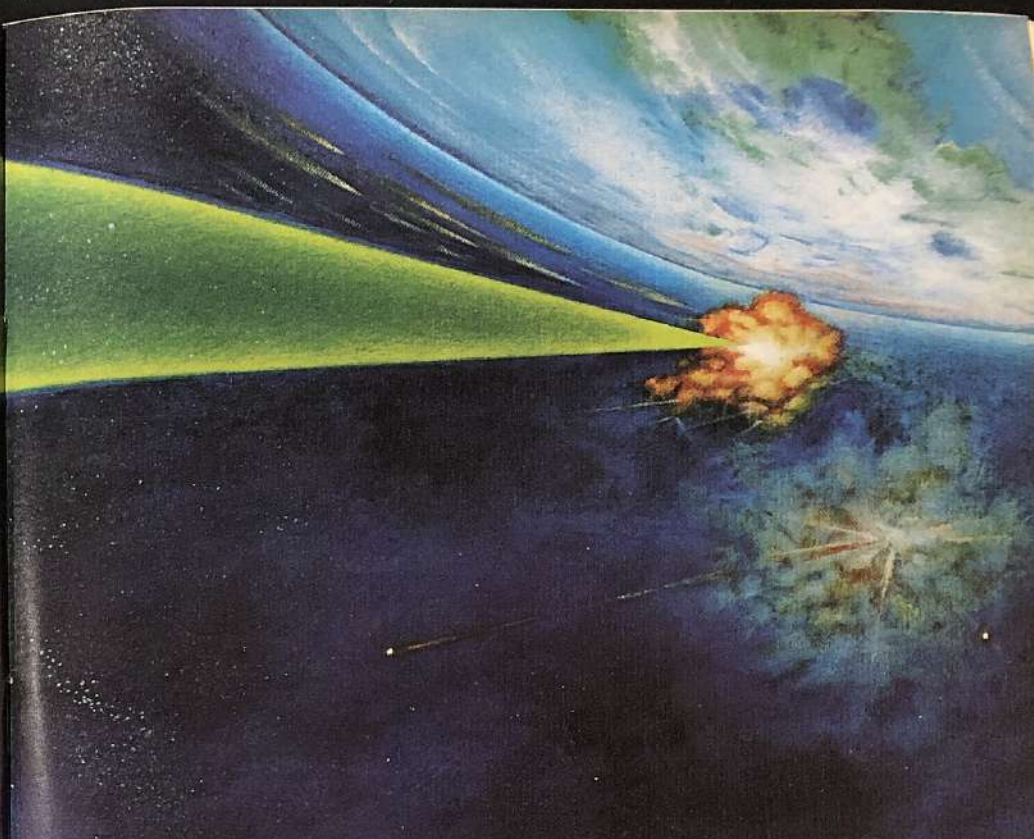
To its backers, the laser seems the perfect weapon. Traveling in a straight line at 186,000 miles per second, a laser beam is tens of thousands of times as fast as any bullet or rocket. It could strike its target with a power of many watts per square inch. The resulting heat, combined with a mechanical shock wave created by recoil as surface layers were blasted away, would quickly melt and tear the thin metal skin of an airplane or missile.

Air defocuses and eventually absorbs a laser beam, and rain or clouds stop it in a short distance, but in the vacuum of space its range is limited only by its power and by the precision of the op-

Having demolished one ballistic missile, a laser satellite strikes its second target many miles away. An actual laser beam would be invisible in space, without air or dust to scatter its light

tics that aim and focus it. Thus some advocates argue that a network of laser satellites (a few in high orbit, or more numerous, less powerful ones in low orbit) could stop hundreds and even thousands of ballistic missiles in a few minutes as they rose above the atmosphere.

Not so, says physicist Kosta Tsipis, co-author of the MIT report. He thinks the proposed satellites could be nullified by decoys, electronic jamming, and simple proliferation of missiles—the same countermeasures that made earlier anti-ballistic missile (ABM) systems impractical. An expensive laser satellite would itself be a tempting target, he says, and would inevitably be attacked at the outbreak of war, if not during its assembly in orbit. "You put a billion-



"How we get energy out of coal without taking the coal out of the ground."

"A lot of coal in America—millions of tons, in fact—is too deep or too slanted to be mined by any conventional techniques," says Gulf Engineer Jerry Daniel. "At Gulf, we're working with the Department



Air through injection well supports combustion of coal at A, fire heats coal at B, which produces gas recovered through production well, C.

of Energy on a way to extract the energy from that coal without mining it. We drill an injection well to set fire to the coal. By burning some of the coal, we heat up the rest, which causes it to produce gas. That's why it's called underground coal gasification.

"We had a test burn here in Rawlins, Wyoming, late in 1979, and we're setting up another one. Our hope is that by 1990, industry will be able to use this kind of synthetic gas, which of course will make us less dependent on expensive imported crude oil as an energy source.

"At Gulf, our first priority is to get all the oil and natural gas we can out of resources right here in America. But we're working on a lot of other good ideas, too. Underground coal gasification is one of them; and we're working with synthetic fuels, tar sands, geothermal energy, and other alternative energy sources.

"Overall, you might say that the business we're really in is the business of energy for tomorrow."



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energy for tomorrow.**

Gulf Oil Corporation

"Someday we may use gas from coal the way we now use natural gas."

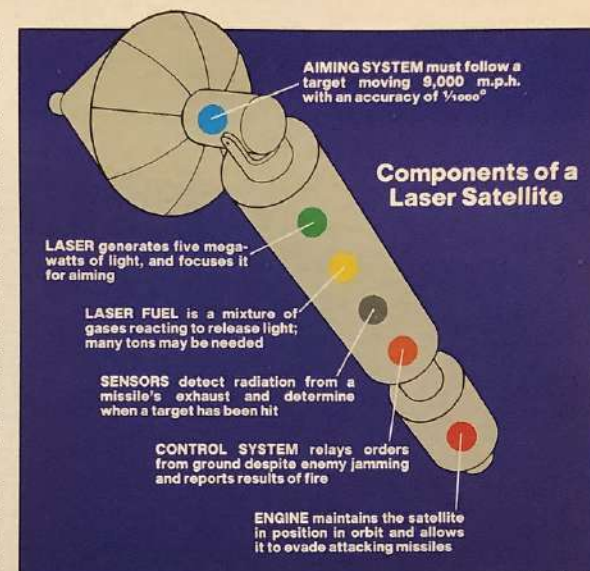
WEAPONS TECHNOLOGY

dollar laser station in space, and I will find a comparatively cheap way to kill it," says Tsipis. "There is no secure way to protect a spaceborne weapon."

Richard Garwin, an IBM Fellow who has been a government consultant on many strategic systems for 30 years, argues that the laser beam's speed alone does not make it a working weapons system. "The Buck Rogers idea—just point at something a long way off and destroy it at the speed of light—is compelling," says Garwin. "The problem is that you've got to find out the target is there, you've got to track it and keep the beam on it long enough to stop it, and you've got to know when you've stopped it so you can switch to another target. And finally you've got to ask yourself whether you're doing your country a service in building an expensive system that may be less effective than a large number of cheaper, more useful weapons."

Senator Malcolm Wallop, a Republican from Wyoming, is one of many on Capitol Hill who believe that a laser defense system would indeed serve the country well; he introduced a bill last year to double the amount of money the Defense Department requested for lasers based in space. Though he concedes that the system would probably be unable to stop all incoming ballistic missiles, he thinks that it could ensure U.S. survival in a nuclear war. Says Wallop, "Of course I would rather save one hundred per cent of our population and military force, but even ninety per cent effectiveness would be a hell of a lot better than throwing up our hands in despair, which is essentially what we've done with the macabre doctrine of 'mutual assured destruction.' The Soviet Union has never accepted that doctrine."

Wallop has some eager allies in the aerospace companies that would build an orbital laser ballistic missile defense (BMD) system. They have lobbied vigorously for an accelerated development program, confident that an effective BMD system could be in place sooner than most people believe. One industry study concluded that a \$10 billion system of 18 "battle stations" could provide an effective defense by the late 1980s. But Edward Gerry, a former director of laser technology at the Defense Advanced Research Projects Agency who believes in the long-term promise of laser BMD, is skeptical. Says he, "From everything I've seen, that particular exercise was quite an under-



estimate of what's needed to do the job, in terms of laser capability and probably in terms of number and cost."

The man in the middle of the controversy is J. Richard Airey, one of the inventors of the high-energy chemical laser, who now manages the Department of Defense program in directed energy technology. His responsibility includes not only high-energy lasers but the still more speculative particle-beam weapons, which like atom-smashers would aim high-energy pulses of charged or neutral particles at a target. "No matter how hard we push," says Airey, "I don't think there will be an effective space-based laser system, with all its command and control systems, before 1990. That makes me a wild-eyed proponent to those who think it can't be done at all, while the enthusiasts complain I don't have enough vision or aggressiveness. But I've dedicated my career to this business. It's a risky business, and I wouldn't be in it if I didn't want to take chances."

The argument that the U.S. should build space lasers stems from the belief of some that the U.S.S.R. has opened a "laser gap." Soon, they say, the Soviets will be able not only to defy the American nuclear deterrent, but also to block any U.S. attempt to orbit laser satellites. Chief among those who

hold this view is former Air Force intelligence director Major General George Keegan (see box, page 66), whose extreme views and warnings of Soviet breakthroughs are considered alarmist by many other intelligence analysts.

But some of Keegan's warnings are echoed on Capitol Hill. "The United States must not be number two," Senator Jake Garn, the Utah Republican, told his colleagues last year. "The implications of a Soviet monopoly on these weapons are staggering." Physicist Bernard Feld, editor of the *Bulletin of the Atomic Scientists* and a persistent critic of the arms race, denies that there is a laser gap. "I haven't seen any persuasive evidence of Soviet breakthroughs, only blatant exaggeration and rumor," he says. "I'm sure the Soviet Union has its own Keegans who are convincing the leaders they ought to work on these weapons, but frankly I would call that a benefit for us."

Research and development for laser weapons has cost the U.S. \$1.5 billion so far, and the expense would grow explosively with a decision to deploy an orbital BMD system. Keegan believes that the Soviet Union outspends the U.S. by 100 to 1 or more in laser weapons research. But after a series of hearings organized by Alabama Senator

"The U.S. Has No Choice"

Major General George Keegan resigned as Air Force intelligence chief in 1977 when he was unable to persuade the CIA and the Defense Department that the U.S.S.R. was taking the lead in laser and particle-beam weapons. General Keegan has since "gone public" with his views, which he set forth in his interview with DISCOVER's Beth Meyer:

The Soviets have already deployed their first particle-beam weapon and the world's largest laser weapon at

General Keegan tells it as he sees it



Howell Heflin, a Democrat, the Senate Subcommittee on Science, Technology, and Space concluded in November 1980 that the Soviet Union's expenditure on high-energy laser technology for military and civilian uses is more like three to five times as great as the U.S. effort.

J. Richard Airey's official position is that if the Soviet Union is indeed moving strongly into laser weapons building, it is probably making a premature commitment. The U.S. effort is dictated by technology and by budget priorities, not by the Soviet program, Airey told the subcommittee a year ago, and weapons development will proceed only when technological questions are answered. That argument leaves industry spokesmen and Senators Wallop, Garn, and others dissatisfied. "If we keep saying 'Wait till next year's improved design,'" says Wallop, "we'll wind up fail-

Saryshagan in the Kazakh Republic, and are testing them. These developments, along with completion of the civil defense system, represent a degree of superiority over the U.S., so imposing that the Soviets will feel free to undertake whatever adventures they have in mind.

The U.S. has no choice but to begin an urgent national crash program surpassing anything since the Manhattan Project. I think that for \$30 billion to \$50 billion we can undertake a number of initiatives in directed-energy weapons that might hold promise of restoring a significant balance within three to five years. Over the past 20 years, we have depended on deterrence—the ability to kill civilians—while canceling or abandoning most programs for strategic and civil defense and slowing the development of new weapons systems. Meanwhile, the Soviets have made history's greatest investment in war preparation. The CIA has kept this from Congress and the public in order to rationalize détente and the unequal SALT treaties.

For the next 20 years the subject of arms control should be wholly ignored because it fulfills the aspirations of only two groups: the liberal press and the Soviet Union. You simply have to do whatever is necessary to discourage the other side from taking advantage, and so you go from each new weapon to the next.

ing behind as we have with tanks. You can toy with potentials until you no longer have any because the other side has pre-empted you."

Opinions about the wisdom of a laser BMD program do not always fall into predictable hawk and dove categories. Paul Warnke, the chief SALT II negotiator and a frequent target of conservatives, says that "a genuinely effective defense would be great; it would put an end to the strategic nuclear arms race." And physicist Herbert York, of the University of California at San Diego, who has repeatedly pointed out that both U.S. and Soviet national security have declined with increasing arms levels, says, "If there were a system that would provide mutual invulnerability instead of mutual assured destruction, I would be one hundred per cent for it. The only problem is that I don't see any effec-

tive system on the way using lasers, particle beams, or anything else." It is the sheer destructiveness of nuclear weapons that makes mutual invulnerability so hard to achieve; a mere 1 per cent of the Soviet strategic force could destroy more than 50 of the largest U.S. cities; Soviet cities are similarly vulnerable.

As it weighs the arguments about laser satellites, the Reagan administration will have to consider a bewildering range of possibilities and consequences:

- One superpower could develop and begin to deploy an orbital laser BMD system, and use the first satellites to prevent its opponent from catching up. That might prompt the loser to attack the winner's system before it was completed, or even to use its ballistic missiles in a desperate blow before they became useless.

- The two superpowers could advance roughly in step toward laser BMD systems. If neither side felt too threatened along the way, the long-term result might be mutual invulnerability and the scrapping of the ballistic missiles—or it might be simply a shift in strategic emphasis to low-flying cruise missiles or other weapons.

- Countermeasures against laser satellites could prove effective, encouraging a treaty like the ABM treaty of 1972, which became possible only when both sides concluded that an attacker could always add warheads and decoys more cheaply than a defender could intercept them.

- The present treaty forbidding nuclear weapons in space, the ABM treaty, and the tentative negotiations already begun on anti-satellite warfare could be expanded step by step to cover spaceborne lasers as well.

Beyond the argument over whether working space lasers will appear tomorrow, ten years from now, or 20 years from now lies the certainty that sooner or later they can be built. The laws of physics do not forbid them; the constraints of technology and economics make them difficult to build, but not impossible. Only political decisions can bring them into being or rule them out, and those political decisions will be shaped—as they have always been—by hope and by fear. Each side hopes to escape the nuclear threat, and fears that if the other does so, it will use its invulnerability to rule the world.

In the first few years after its invention in 1960, there seemed few applications for the laser, which was often called "a solution looking for a problem." But all that has changed, for the laser may soon be both.

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TIME TO HALT THE RETREAT FROM SPACE

A renewed program would broaden the frontiers of technology, as well as of the mind and spirit

by DENNIS OVERBYE

 In the dim, frigid outer reaches of the solar system, beyond the gaze of earth's most powerful telescopes, a fragment of the primordial cosmos, a chunk of snow, gas, and dust left over from the formation of the solar system, is slowly falling sunward, tracing tiny but ever growing loops on the sky. In 1986 this celestial iceberg will swing around the sun, blazing with reflected glory; sunlight will blast gas and dust off its ancient surface into a glowing tail millions of miles long. As it has done every 76 years or so since the beginning of history, Halley's comet will have returned to dazzle and frighten the human race.

This time will be different. As the comet makes its run at the sun, a small fleet of three spacecraft will be making its own run at the comet, sniffing and analyzing the comet's dusty, gaseous corona, hoping to photograph its boiling, turbulent nucleus, which is believed to be a pristine remnant of the birth of the solar system. One of the three spacecraft will be Soviet, one a European joint venture, and one Japanese. There was to have been a fourth spacecraft, the most sophisticated of them all, equipped with the latest generation of the cameras that photographed the worlds of Jupiter and Saturn: the American one. But it was left on the budget-room floor; barring an eleventh-hour

rescue by the Reagan administration, it will not be there.

During the past two decades, more than 3 billion years after life began on earth, human beings have taken their first faltering steps off their own planet. American spacecraft, in particular, have crisscrossed the solar system, visiting a new world on the average of once a year. What were wandering lights in the sky to the ancients or wavering blobs in a telescope eyepiece have become places—cracked and cratered, smooth and dusty, smogbound, bare and burned—replete with deserts, sulfurous cloud banks, giant volcanoes, winding canyons, hurricanes, acid rains, and perhaps methane swamps. Some of these places bear human footprints or other memorabilia. That explosion of exploration has been as remarkable in its way as if, say, a sand crab crawled out of the Pacific at Malibu, hitchhiked to New York and then went on to tour Europe, sending back snapshots of the Empire State Building and Chartres cathedral. No generation of humans has ever come so far so fast, but the impetus, at least on this side of the Atlantic, may already be waning. In August, Voyager 2 will follow its sister past Saturn, but after that no planet, moon, or comet will be visited by an American spacecraft for five years—the longest dry spell since space exploration began. As Voyager 1 rounded Saturn and headed off into the void last No-

vember, space scientists were contemplating another kind of void.

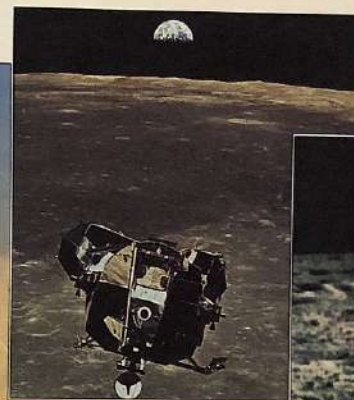
There is still the magic year of 1986, when Voyager 2 will reach Uranus and when a proposed radar-imaging orbiter will arrive at Venus. (The two-shot Galileo mission scheduled to arrive at Jupiter and go into orbit in 1986 has been delayed another year.) But beyond that nothing at all is planned. It takes years to build and launch a spacecraft like Voyager; if scientists and the government agreed today to go digging in the methane drifts on Titan or to rove the red sands of Mars, it would be the end of the decade before either of those missions reached its destination.

Two decades after it all began, the U.S. space program is at a turning point, afflicted by a malaise. Has America retreated from space? Can the nation afford to explore the universe and plant men in space? Can it afford not to?

American space enthusiasts might envy their Soviet counterparts, who are planning to bombard Venus with probes in the 1980s and who talk about a manned mission to Mars in the decade beyond. The Soviet space effort has played tortoise to the American hare. Ten years ago Americans were strutting on the moon; now it has been almost six years since any American has been in space. Meanwhile Russian cosmonauts and an international array of guests have been coming and going like weekend tourists at their own little cot-



Apollo 8 leaving to circle the moon in 1968



Earthrise as seen by Apollo 11



Astronaut Edwin Aldrin on the moon

tage in the sky, Salyut 6. They have accumulated some 47,000 man-hours of space-flight time, compared with only about 22,000 for Americans.

Sometime in the next few months, the U.S. will get its brand-new chariot to the stars, the space shuttle, and will begin to catch up quickly with the Soviet manned-space records. But to what end? NASA built the space shuttle without a long-range program for its use, and was in fact expressly forbidden to plan the next step in space. Meanwhile the shuttle's \$8.9 billion cost and lengthy delays ate away at the agency like a hungry black hole, swallowing some programs whole and nibbling at others. Caught between the budget cutters in the White House and its own timidity, NASA tried to play it safe. It optimistically attempted to develop the craft on a shoestring, gambling on making no mistakes, and failed. Congress rescued it with further appropriations. Some think that the shuttle itself would not have survived its fiscal ordeals had it not been needed by the Air Force for launching spy satellites.

A race is not the only reason for going into space, but it is unrealistic to ignore the fact or appearance of competition. Those dreamers who see space as the next evolutionary ground for the human race are not above beating the drums of national pride now and then, as they did in 1961. The drums can be heard loud and clear today, but there

are two contradictory messages. On the one hand, there is the Reagan administration's stated wish to restore American technology and productivity to a position of pre-eminence. Space is, literally speaking, the high ground, technologically as well as militarily. On the other hand, NASA's roughly \$6 billion-a-year budget has been eyed as a likely target for big cuts by Reagan's budget director. Luckily, NASA's budget has a strong supporter in the person of geologist-astronaut Harrison Schmitt, chairman of the Senate subcommittee on science, technology, and space, who roamed the moon with Apollo 17.

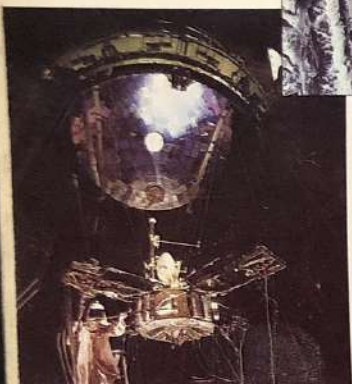
The predicament of the American space program today results in part from its genesis as a propaganda effort. "We came in peace for all mankind," reads the plaque that the Apollo 11 astronauts left on the moon. But that was only partly true. As sociologist William Bainbridge points out in his book *The Spaceflight Revolution*, the moon was as much a part of the cold war as Vietnam was. "At least," he writes drily, "no natives were killed on the moon." Carl Sagan has remarked that Apollo should have been part of the State Department's budget.

Forced to share the evening news with Vietnam, the later moon landings became merely one more technological excess, a sign of national hubris, a

wasteful escape from social realities at home. In all, 43 Americans flew in space; all were white, male, and Christian. When the Great Society began to come apart, a space program that had never been sold on its own merits was an easy target for both opportunistic congressmen and social critics; their wrath had nothing to do with science. There is a myth abroad in the land, and especially among some scientists, that many people do not like science and are embracing irrationalism and superstition—a myth that educators, publishers, and TV producers, among others, might dispute. Even those who are afraid of science need science.

A thousand years from now, the last half of the 20th century will almost certainly be remembered more for those footprints on the moon than for Watergate or OPEC or even for designer jeans. Perhaps America will have returned to the moon by then and built a monument to keep the cosmic rays and interplanetary tourists off Neil Armstrong's and Buzz Aldrin's bootprints. History may record that the United States did the right thing for reasons that were not entirely the right reasons.

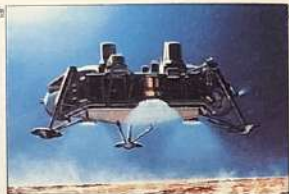
The atoms in man were forged in the stars; the energy that moves his body is generated in the sun, 93 million miles away. The cosmic-ray winds that blow through the solar system and irradiate creatures on earth may be gradually rewriting genetic codes, helping to drive



Mariner 4 prepares to visit Mars



Valley Marineris on Mars; Viking lands on the red planet



Martian sunset

evolution. The universe is man's environment, and the urge to explore that universe is part of the universe. In exploring it, man explores himself. Who can say, on this battle-scarred, polluted planet, that man already knows enough about himself?

In this lean age, space ventures must also be justified by practical pay-offs, grist for the balance sheet and the cost-benefit analysis. NASA shot 24 billion Apollo dollars into the air, and it rained back down technology, as well as prosperity and pride. Most Americans are familiar with some of the pay-offs: Velcro fasteners, microelectronics, photograph enhancement, weather and resource satellites, navigation and communications satellites. Fewer know that in Florida, a version of a camera developed to measure surface features on Mars is monitoring the repair of cleft palates. That after the Boston marathon last year, cold, exhausted runners wrapped themselves in blankets of metalized film invented for insulating spacecraft. That the techniques used to program remote satellites are now employed to program heart pacemakers already implanted in countless patients.

The technological rain is still coming down, but unless the atmosphere changes, it will eventually dry up. To unshackle NASA after its recent penurious years would be to liberate the best instincts of American inventiveness.

There are minerals on the moon, iron and nickel in the asteroids, water in the rings of Saturn, and energy in the sunlight. Where robots have been, human beings will find a way to live and work. At a space station, under weightlessness, special alloys and crystals that are impossible to produce on earth could be manufactured. From a space station, eyes and ears unhindered by the earth's murky atmosphere can look out on the universe. They can also look down.

In fact, scientists are only beginning to be able to study the earth from the vantage point of space, perceiving its weather, geology, and vegetation in large patterns invisible to surface dwellers. What they can learn may eventually teach them how to take care of the planet. In 1972, Landsat photographs showed disaster shaping up in the Soviet wheatfields, leading Agriculture Secretary Earl Butz to predict that the Russians would be buying massive amounts of American grain that summer. But nobody paid any attention.

Some day it may be said that man had to leave the earth in order to find it. From space he first got to see his own planet, floating above the barren moon-landscape like a blue marble. Perhaps more than anything else, this view of the earth dramatized the world's uniqueness and fragility and gave impetus to the environmental movement. In order

to understand and perhaps survive the earth's evolution, scientists will need to know why Venus, one of the earth's two closest planetary neighbors, is a choking inferno in a "runaway greenhouse" of carbon dioxide. And why Mars, the other neighbor, is an arid, rocky desert cut by what may be the beds of ancient rivers. How narrow is the line between those deathly extremes? The Vikings, Voyagers, Pioneers, and Mariners—all the talented robot cruises—were investigations into what makes a world. The worlds explored in the past two decades are more varied than expected, but none of them is alive, not yet.

Man is part of an evolutionary process that is out of his control. Within the next generation, it seems, he will begin to find out whether he can establish a place for himself beyond his native planet. Whatever the outcome of this experiment, mankind's view of itself and its home planet is likely never to be the same. If human beings find themselves bound to the earth, they may feel compelled to try to preserve it.

It is time for a real American space program again, one that will not languish a decade later when the fashions change. The shuttle is a good first step. The next should be the establishment of a space station in orbit around the earth. Such a station could be constructed from parts transported into orbit by the space shuttle, and would serve as a



Spacecraft view of Mars



Simulation of Voyager 2 at Saturn



Jupiter's moon Europa



Active volcanoes on Io



The space shuttle awaits launch

scientific outpost as well as a staging area for deep-space forays and satellite launches. It would give man a permanent foothold on the edge of the new New World. Make the station a place where all of humanity could come in peace. The technology entailed in building it would be its own reward, as would be the nation's almost forgotten pride. The investment would be an investment in technology, in the future.

Look down at America from a high place, say two hundred miles. The lesson from space is a seamless interdependence that no wall of missiles can close out. Arms have never saved a people who ceased to be animated from within. The ideas that animate Americans are freedom and justice, but they are linked somehow to the frontier, that limitless West of possibility. Americans are a rambunctious people who get surly when they feel closed in. The frontier mentality is dangerous in a highly structured urban society. For a people whose idea of fun is riding wild bulls, or chasing rattlesnakes, or watching 250-pound armored men crash into each other on Sunday afternoons, space may be the safety valve for restless spirits.

Those who go are likely to be a varied bunch, a combination of the best and the brightest, the hardest and the most foolhardy, the disaffected and the most aggressive. Stewart Brand, professional counterculturalist and editor of the

Whole Earth Catalog, sees space colonies as the 21st century versions of collectives and communes, where new modes of living, new perspectives may evolve. Says he, "Those who choose to stay behind will be writing a love letter to earth. Those who go will face hardships in space that will oblige a life-and-death reliance on each other that is the sort of thing people romanticize and think endlessly about, but seldom get to do."

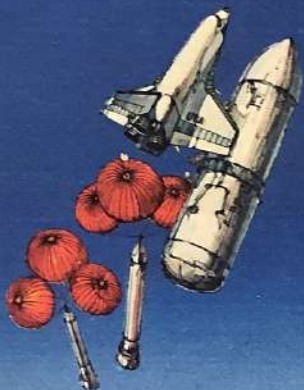
The will is there. The tight cadre of visionaries who seduced Kennedy and Khrushchev into a moon race have been swelled by the *Star Wars* generation. The past few years have seen the proliferation of groups like the L-5 Society (named for a particularly convenient point in earth orbit to set up a permanent space colony), the World Space Foundation, Citizens for Space, the Planetary Society, and dozens more, whose mission is to promote space exploration. In Pasadena, a group of people are building a solar sail, which will be launched from a rocket or the space shuttle and be propelled by the pressure of sunlight. Some day solar sailors may cruise the asteroid belt.

On a red, rock-strewn plain named Chryse Planitia (golden plains), 50 million miles from home, a robot sits, covered with the dust and frost of Mars, keeping a lonely vigil. At its feet, the Martian surface is scratched where Vi-

king I dug, looking futilely for some clue to signal the end of man's cosmic loneliness. Time has largely immobilized the first Viking lander. But after four and a half years, it still sends pictures and data back to earth every 37 days. Viking has kept the faith; NASA scientists believe it could report from Mars for the rest of the century.

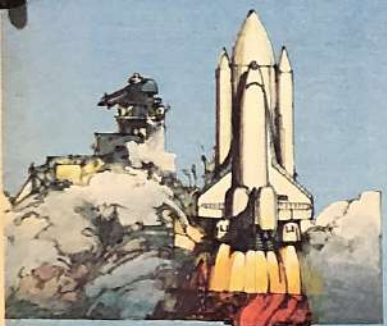
The question was whether NASA could afford the relatively paltry amount of money needed to go on listening to mankind's only outpost on another planet. In the late 1970s, when it was announced that the spacecraft might have to be turned off, a group of space scientists and engineers organized a fund-raising drive to keep it alive. On a snowy January day at a small reception at the National Air and Space Museum in Washington, D.C., Stan Kent, an organizer of the Viking Fund, handed NASA administrator Robert Frosch a check for \$60,000—enough to keep the Viking operation going for two months—and a promise of more to come. The money was contributed by more than 10,000 people in an outpouring that overwhelmed NASA. It was a poignant day for an agency that has spent billions, but it spoke volumes about the determination of the people. The future belongs to them, and the future is in space. □

All aboard for outer space



2. The spent booster rockets parachute back to earth so that they can be used again. The fuel tank, however, will drop into the Indian Ocean

1. March 17 or later: Lift-off! The shuttle orbiter is dwarfed by its own fuel tank and two slender booster rockets



It has been called a "brick cloud" and "America's space lemon." But no longer. As America's first space shuttle, the Columbia, sat on its launching pad at Kennedy Space Center, bathed in spotlights, its towering assembly of tanks and booster rockets looked like nothing so much as a magical City of Oz. Sometime after mid-March, the Columbia, carrying a two-man crew, will blast off that pad on its maiden flight into space. After ten years and \$9 billion, NASA engineers and officials are beginning to feel that they can see the end of the yellow brick road.

Designed to take off like a rocket and land like a glider, the Columbia is the world's first reusable spacecraft. The mighty (and expensive) Saturn 5 moon rockets fell into the ocean after launch, and the returning Apollo capsules, charred by the heat of re-entry into the atmosphere, were simply plucked out of the ocean and trucked off to museums. When the space shuttle comes down, it will be swept out, cleaned up, and sent back up again.

By the end of the decade five currently planned shuttles should be making dozens of trips a year into orbit, their 15- to 16-ton payloads of satellites, scientific experiments, military payloads, and passengers. The goal is to make space accessible, and going there economical and almost routine.

Getting the Columbia to the launch pad, however, has been anything but routine—largely because of a stingy (by Apollo standards) budget. Problems plagued the shuttle's reusable rocket engines, which are on the cutting edge of the technology; each shuttle craft has three of these, each capable of generating 470,000 pounds of thrust. During a practice firing in December 1978, for example, an untested valve failed and the engine exploded.

The Columbia also developed a skin disease. Its aluminum body is covered and protected during re-entry by a permanent heat shield (those on the old space capsules were good for only one trip, burning beyond repair during re-

entry); it consists of more than 30,000 ceramic tiles, each custom made for its place on the spacecraft body. But the tiles turned out to be weaker and more brittle than expected, and they were not properly bonded to the spacecraft. When the Columbia was ferried by 747 from California to Florida in 1979, some of the tiles fell off. For more than a year and a half, Columbia sat in a hangar at Kennedy while workers swarmed over it, pulling off tiles, testing them, putting new ones on, and testing them again.

NASA engineers now believe they have licked the tile problem, but some engineers fear that the loss of tiles during re-entry could lead to the loss of the spacecraft. Kenneth Kleinknecht, the shuttle orbiter manager, is undaunted. Says he, "If we don't have the confidence, we won't fly it. Simple as that."

Thousands of workers lined up at Kennedy Space Center in December to watch as the shuttle-mated belly to belly with its fuel tank and loaded booster rockets—emerged aboard a crawler

from the giant vehicle assembly building. The old Apollo spirit was in the air. Once installed on the launch pad, the shuttle faced a busy schedule of tests: a last crucial firing of all three engines at once; a fancy new, but unproven, computerized countdown system; and the first filling of the giant external tank with its frigid fuel (engineers are afraid that ice building up on the outside of the tank will flake off during the launch and damage the fragile tiles).

Later this spring, if all goes well, astronauts John Young and Robert Crippen will finally blast off from Cape Canaveral, riding a plume of smoke and fire into the future. This is the first time that men will be aboard the maiden flight of an American spacecraft.

Their 55-hour flight should open the door to more spectacular and routine uses of space in the 1980s. When Columbia takes off, the whole world will be watching. But by the end of the decade, shuttle launches will generate only yawns. That is exactly what NASA has in mind.

—D.O.

3. During their 36 earth orbits, the astronauts will check out the shuttle's maneuvering systems, preparing for more spectacular missions like the launch, pictured above, of a satellite from the shuttle's cargo bay

4. Columbia will literally blaze across the sky during re-entry as friction with the atmosphere heats its outer surface to more than 3,000 degrees Fahrenheit

5. Their every move monitored by on-board computers, the astronauts will glide down to the desert at Edwards Air Force Base in California



June 1981

DISCOVER

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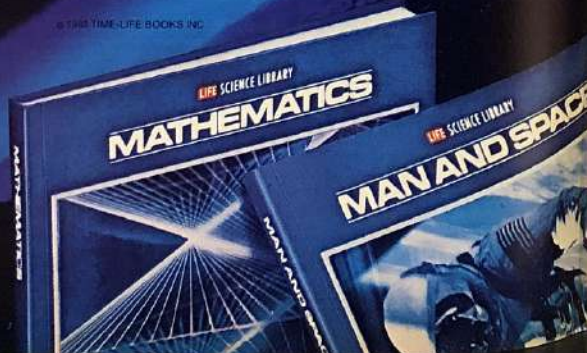
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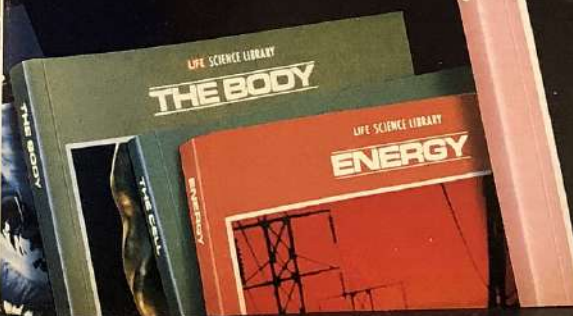


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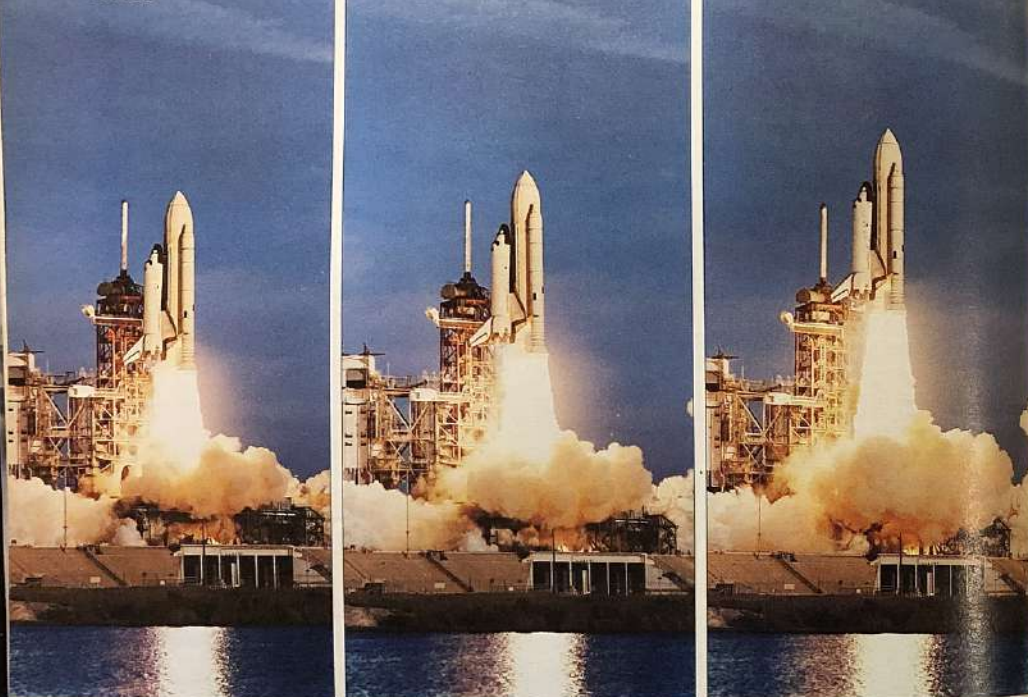
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SPACE



"T minus 20 seconds and counting. T minus 10, 9, 8, 7, 6, 5, 4, we have gone for main engine start, we have lift-off of America's first

COLUMBIA, GEM

The space shuttle has returned Americans to space, but what will they do there?

Flat and white as spilt milk, the cracked mud of Rogers Dry Lake sprawls twelve miles across California's Mojave Desert, 60 miles north-east of Los Angeles, framed by rolling hills of sagebrush and clear blue skies. From the air, the circles and long dark lines painted in oil across its surface look like a mysterious shuffleboard court of the gods. As the sun climbed higher on the morning of April 14, a mirage began to fill the lake bed with what to hundreds of thousands of spectators seemed to be water. At about 10:20 a.m., as most of the throng watched a pair of T-38 jets curving

south, two sonic booms cracked across the desert. Cheers rose from the shore of the lake bed. The space shuttle Columbia, traveling just over the speed of sound at 54,000 feet and falling two and a half miles a minute, was coming home from space.

That thunder announced not just the arrival of Columbia and the end of a perfect first flight for the space shuttle, but the arrival of a whole new era in manned space flight. For NASA the moment was one that had long seemed to shimmer like a desert mirage, just out of reach, as engineers struggled to get the overdue and over-budget spacecraft

off the ground. But for three days in April, those problems had been mostly forgotten as the nation and the world almost nostalgically relived a familiar drama: the spotlighted rocket; the tense countdown with shirt-sleeved engineers worrying through last-minute glitches; the staccato gut-punching roar of lift-off; the flat, terse radio chatter; the laconic, unruffled astronauts floating around their cabin, exchanging corny jokes with Mission Control in Houston; the waiting wives. When the flight ended, however, it was time for something completely new. Columbia was not only coming home, it was coming home with



space shuttle."—Launch Control, April 12, 1981

OF A NEW OCEAN

by DENNIS OVERBYE

dignity, gliding to earth on its stubby delta wings instead of falling like a rock into the ocean.

As the Columbia shot high across the lake bed, spacecraft commander John Young, 50, took over the controls from the four computers that had run most of the flight so far and banked into a sweeping turn to bring the spaceship in line with the runway painted across the lake floor. Looping over the old mining town of Boron, the Columbia came out of the final turn at 12,000 feet and 310 miles an hour, and headed for the desert floor. As he approached the lake bed, Young pulled the spacecraft's nose

up, cutting its air speed to about 200 miles an hour; landing gear popped out of its black-tiled belly. "Pick up your feet," crackled a chase pilot. The DC-9 sized Columbia, kicking up a rooster tail of dust, touched its main landing gear smoothly to the ground, then its nose gear, and rolled to a stop. After Young finally emerged, he strode up and down the length of the ship, inspecting its fragile tiles, waving his arms and punching the air, grinning, and shaking hands with the ground crew. His demeanor showed what inspection teams would later verify: Columbia had survived its journey to space and back vir-

tually unscathed, and with only a little work would be ready to go up again.

Said Young, "We're not too far, the human race, from going to the stars." Echoed his traveling companion, astronaut Robert Crippen, 43, "We're really in the space business to stay." Many Americans seemed less excited about the possible conquest of space than about the vindication of American technological prowess. Launch director George Page waved a small American flag at Kennedy Space Center in Florida, and said, "I think they [the Soviets] would be very happy to have something like we had today."

PHOTOGRAPHS BY WAYNE SORCE AND HANK MORGAN

The mission that put Americans back in the space business had begun with a false start. On Friday, April 10, Columbia had come within nine minutes of launch when a stubborn computer malfunction reawakened the fears of those who were afraid that the shuttle would be NASA's technological Vietnam. The spacecraft is controlled by a committee of four computers processing the same information and cross-checking the results several hundred times a second. Any dissenter from the silicon consensus is rudely thrown out. If a stalemate develops after that, a fifth, backup computer is called upon to take over. That Friday the four primary computers, in perfect sync with each other, found themselves one twenty-fifth of a second ahead of the backup computer. When they tried to communicate with the backup, it would have nothing to do with them; in the world of computers, being a twenty-fifth of a second early or late is an unpardonable gaffe. In the words of a NASA spokesman, the backup "hung up the phone" and complained to its handlers. Consoles at Launch Control at Kennedy and Mis-

sion Control in Houston lit up like penny arcades. The solution eventually turned out to be simple: turn all the computers off and start them again.

The first flight was two and a half years overdue, but Young and Crippen had made good use of the long delays. In fact, they had to counter suggestions that they might be overtrained and, like athletes, have lost their edge. Young, a retired Navy pilot, was one of the most experienced spacefarers in the world, a veteran of four previous flights, including two trips to the moon. Asked how he got the coveted assignment to command the first shuttle flight, he replied, "The chief of the astronaut office makes the recommendation. At the time, I was the chief." Crippen, still a member of the Navy, was chosen for the Air Force's Manned Orbiting Laboratory, later abandoned, and then joined NASA; in 14 years as an astronaut he had never made it to space. On the Saturday morning after the scrub, Crippen and Young were repeating their old routine, flying simulated shuttle landings in a modified Gulfstream jet. The next morning they ate another

lift-off breakfast, of eggs and Canadian bacon, and climbed into their spacecraft. This time the word was go.

At precisely 7 a.m., as the computer-controlled countdown wound to an end, pale orange fire squirted from the orbiter's three main rocket engines. Within seconds, as the computers ascertained that those rockets were firing properly, the two solid-fuel boosters ignited, adding more than 5 million pounds of thrust to the 1.1 million from the main engines. The shuttle, a Taj Mahal of tanks and towers, jerked up from the pad, rolled its fat belly toward the west and the cheering spectators below, and rose swiftly on a pillar of smoke and yellow fire out over the Atlantic. "Go baby, go!" yelled a reporter, but it was clear that the Columbia needed no encouragement.

In two minutes the boosters burned out and were jettisoned into the Atlantic, where recovery ships, outmaneuvering a Russian trawler, later picked them up; they were pronounced fit to fly again. Columbia's main engines burned for eight minutes, almost until orbit. "Confirm shutdown," re-

ported capsule communicator Dan Brandenstein in Houston as the engines went quiet. "Columbia the gem of this new ocean, now in space, not yet in orbit." The external tank was cast loose to fall into the Indian Ocean (NASA did not want the tank going into orbit and creating another falling-Skylab scare). A series of burns with its two orbital maneuvering rockets pushed Columbia into a 169-mile-high, nearly circular orbit.

Columbia was the first American spacecraft to carry a crew on its maiden trip into space, and its main job was just to get up and down safely. NASA officials had hinted that the shuttle might not stay up for the entire fifty-four and a half hours planned. But Columbia passed every test like a veteran and turned in a mission that was, in NASA's understated word, "nominal"—right on the money. Columbia's maiden voyage produced no serious problems—what flight director Neil Hutchinson calls "show-stoppers." From above, the astronauts pronounced the craft "outstanding." Said Crippen, "This vehicle is performing like a

champ." Aloft for the first time, he also enjoyed the view. Said he, "It's hard to get my head in the cockpit here." In fact, the difference between the veteran and the rookie was evident on lift-off, when Crippen's heart raced to 130 beats a minute while Young's dawdled along at between 85 and 90 (curiously, the pattern was reversed at re-entry).

The most crucial test came about two hours into the mission, when the astronauts had to open and close the cargo bay's clamshell doors. Engineers feared that stresses during lift-off or heat from the sun would distort the doors, jamming them open or closed. Not only would that make it rather difficult to carry out projects on future flights, but radiators on the insides of the doors are used to cool the orbiter. Trouble with the doors would have required an early return, and had they jammed open, Crippen would have been forced to take a space walk to close them. But the doors worked perfectly.

The closest thing to a show-stopper came when the cargo doors were open and the astronauts could aim a televi-

sion camera out the rear windows at the tail section. Millions of TV viewers on earth could see the problem: ominous black patches on the rear engine pods, where at least 15 tiles had come off.

In Houston, engineers quickly determined that those particular tiles would not be missed during re-entry. But suppose some tiles had also fallen off the shuttle's unseen underside, where friction during re-entry would generate temperatures close to 3,000 degrees Fahrenheit. A hole burned in the wrong place could endanger the ship and crew. Looking for clues, NASA officials reviewed films of the launch, studied data from on-board sensors, and arranged for the shuttle to be photographed by secret military telescopes at Malabar, Florida, and Maui, Hawaii, that are usually used for studying Russian spy satellites. The next day, from Houston, deputy flight director Eugene Kranz read a tightly worded statement to the effect that NASA saw no reason to change the planned re-entry procedures, and that experts believed that the underside tiles were all in place.

The main cargo and the prime exper-

PHOTOGRAPH BY HANK MORGAN



Columbia touches down at Edwards Air Force Base

SPACE

iment of Columbia's mission was the spacecraft itself; it was wired throughout with strain gauges, accelerometers, and thermometers—even under and between the thermal tiles—to monitor its performance. The most serious snag of the entire voyage occurred when one of three tape recorders receiving the flight data stuck in the "continuous recording" mode. Had it kept operating, it would have run out of tape before it could have recorded the all-important thermal data during re-entry. But the astronauts found they could turn it on and off with a circuit-breaker, and the data were saved. Crippen, floating upside down in zero gravity, tried to remove the stuck recorder from its box, but some of the screws were too tightly fastened for him to budge it.

Bulky flight instrumentation took up the space that ordinarily will be occupied by sleeping compartments, so Young and Crippen had to sleep in their ejection seats. They were able to enjoy the other amenities of the shuttle, however—such as the spacious mid-deck, with a heater for warming food trays, and a fancy new zero-gravity toilet (until it broke down near the end of the mission). They were also treated to a rare sight. On their first (earth) night out, they saw an unusual display of auroras across the southern United States—the result of a powerful solar flare. The astronauts were warned that this burst of solar radiation, while posing no danger to them, might set

Columbia's cargo bay gleams in the sunshine of outer space. The starboard engine pod is missing some tiles

off the spacecraft's smoke alarm. It did not. Meanwhile, Crippen, like a kid on a Sunday drive, could not restrain himself from pointing out the sights. "Looks like we're going right over Chicago. Or are we lost in space again?" Mission Control: "No, we think you're probably right."

The moment of truth came two days, five hours, and 21 minutes after lift-off, over the Indian Ocean, when Columbia, traveling stern first, fired its orbital engines once again to brake its velocity and begin the long fall home. Twenty-five minutes later, its nose pointed 40 degrees above the horizon, Columbia re-entered the atmosphere at an altitude of 400,000 feet, traveling at 25 times the speed of sound. For about 16 minutes, Young and Crippen rode inside a pink fireball, their radio communications blacked out by the heated ionized air around the spaceship, now rapidly becoming an airplane with a glowing nose.

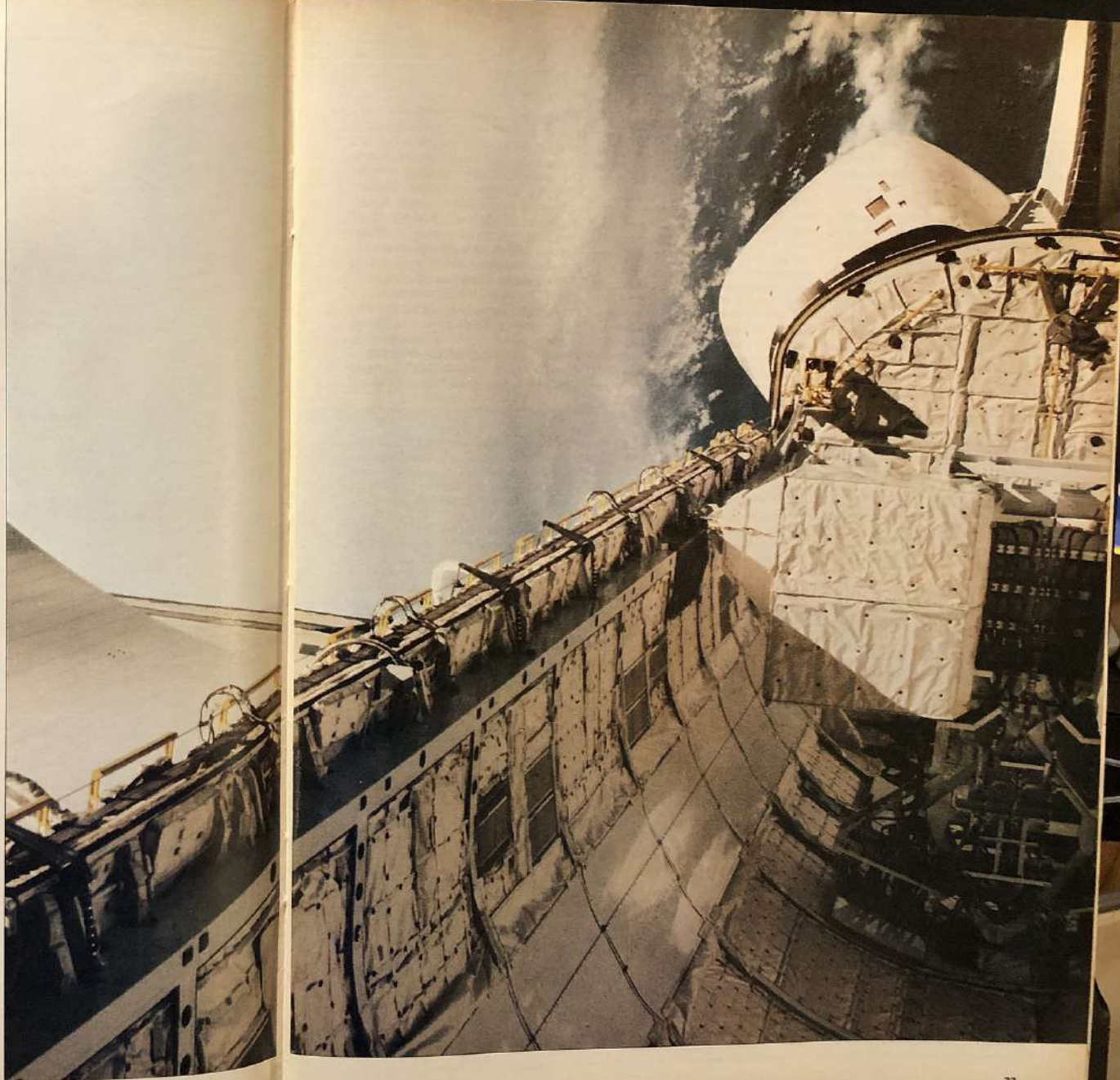
They emerged from blackout just off the California coast, and radioed a cheery "Hello Houston, Columbia here." A mountaintop television camera caught the first glimpse of the spaceship. As it approached the coastline at 4,000 miles an hour and 130,000 feet high, right on the planned track, Young wrested control from the computers and swung the craft back and forth in wide S-turns to slow it down. Cracked Crippen, "What a way to come to California." The rest was all television.

"We've just become infinitely smarter," said Chris Kraft, director of the Johnson Space Center at Houston. As the astronauts surrendered Columbia

After shaving, Young cleans his razor



Crippen does acrobatics



to the ground crews, jubilation swept Mission Control. Workers placed the Columbia's medallion on the wall next to the Apollo and Gemini plaques; deputy flight director Kranz wept before lighting up a big cigar.

The next chance to become smarter will be in late September or early October, when astronauts Joe Engle and Richard Truly take Columbia back up for a four-and-a-half-day flight. That trip will be the first to carry a scientific payload—a pallet of earth-monitoring instruments designed to do such things as map geological features with radar, sniff for air pollution, and measure the distribution of algae in the oceans and vegetation on the land. Engle and Truly will also test the shuttle's remote ma-

nipulator arm, which will be used to pluck things out of the cargo bay and toss satellites into orbit.

Two more test flights of longer duration will occur in 1982 before the shuttle is deemed ready for regular operation. All these flights are scheduled to depart from Kennedy and land at Edwards Air Force Base in California. But once the shuttle is operational (or perhaps sooner), it will also land at Kennedy, on a new 15,000-foot runway.

The second shuttle, Challenger, is now being tiled and assembled at Rockwell International in Palmdale, California, and is slated for delivery in June 1982. The third and fourth, Discovery and Atlantis, should make their first trips to space in 1984 and 1985.

Columbia's success showed that it is possible to visit space routinely, but mankind still has to decide what to do there. As Rockwell vice-president George Merrick said two weeks before the flight, "I wonder sometimes whether the country is ready for the success of the space shuttle." NASA's first scheduled task in the space trucking business will be to haul into orbit the first of four tracking and data-relay satellites owned by the Space Communications Company. NASA plans to lease channels on these satellites to provide future shuttle flights with continuous communication with controllers in Houston. (Young and Crippen spent a good part of their trip saying hello and goodbye as they passed in and out of

range of various radio ground stations.)

Communications satellite launches for both business and foreign governments make up a large part of the bookings for the first 68 flights, which run through the fall of 1986. The cost of a shuttle flight is about \$35 million in 1981 dollars, but four relatively small satellites and their booster rockets can fit in the cargo bay at once; this means that a satellite can be launched from the shuttle for as little as \$9 million—a real bargain in the space age. For another \$9 million or so, depending on options, users can rent the European-built Spacelab—a shirt-sleeve laboratory that fits in the cargo bay. In the long run, the most important benefits of nearby space may be the availability

of its nearly perfect vacuum and zero gravity ("microgravity" is the term preferred by space-industry buffs). Under these conditions, exotic new materials, such as foamed aluminum, can be produced and certain kinds of manufacturing carried out more efficiently than on the ground under gravity's heavy hand. So far, few companies have been willing to invest the large sums of money required for industry in space. But now that the shuttle has been shown to work, NASA expects business to pick up.

A few big customers took the plunge even before Columbia's success. The West German government has booked two Spacelab shuttle flights to experiment with processing materials in

microgravity. McDonnell Douglas and Ortho Pharmaceuticals have reserved a Spacelab to test a way of extracting enzymes and hormones by using electrical fields to separate them from surrounding biological material. (The process, called electrophoresis, should work better in microgravity.) NASA is giving the McDonnell-Ortho collaboration a free ride. If the experiment is successful, the two companies envision putting a commercial plant in orbit in 1986.

The microgravity game is not limited to governments and big corporations. For \$3,000 to \$10,000, with only \$500 down, any individual or group can play space scientist and send up on the space shuttle a self-contained experiment weighing as much as 200 pounds and oc-

The Tiles That Took the Heat

Of all the problems that plagued Columbia before its successful flight, none was more vexing—or more puzzling to the public—than that posed by the shuttle's 27,000 heat-resistant tiles. Designed to protect the shuttle and its crew from the searing heat of re-entry, they proved difficult to attach and showed an alarming tendency to fall off. Indeed, a

covering layer of tiles on the shuttle seems an anachronism in the space age, evoking images of do-it-yourself bathroom-tile kits. Among the questions raised by the tiles, and the answers:

Why is the shuttle's skin not made of metal or the heat-shield material that protected earlier spacecraft?

The shields for Mercury, Gemini, and Apollo capsules dissipated heat by "abating," or slowly charring and breaking away in white-hot fragments—no solution for a re-usable spacecraft. Certain alloys, such as Inconel, could withstand the heat, but they are too heavy and would conduct too much heat into the shuttle. (Overlapping Inconel plates are used on the shuttle, but only to provide flexible protection for the hinges of the wing and tail flaps.)

What are the tiles made of?

Columbia's tiles are feather-light blocks of glass fibers, varying from six to eight inches on a side and one-fifth to three and a half inches in thickness, coated with a ceramic glaze. They can withstand temperatures of up to 1,300 degrees Fahrenheit. The shuttle's nose and the leading edges of its wings, which are subjected to the highest re-entry temperatures (up to 2,700 degrees), are protected by a dense com-

posite of carbon and graphite; portions of the upper wing and fuselage that get no hotter than 700 degrees have a flexible skin of silicone-covered felt.

But why use all those little tiles, each of which must be custom-shaped, instead of one continuous layer?

Large expanses of tile material would be too brittle to withstand the inevitable flexing of the shuttle's frame during launch and re-entry, or the heat-caused expansion and contraction of the aluminum skin. Those movements are accommodated by the narrow gaps between the tiles and by the felt "strain isolator pad" beneath each one.

Why was it so hard to keep the tiles from falling off?

When Columbia was flown to Florida piggyback on a Boeing 747, strips of protective tape pulled loose and whipped at the tiles in the 500-m.p.h. air stream. Many tiles were cracked or dislodged. Investigators found that a structural characteristic of the felt pads tended to concentrate stress in the part of the tile near the adhesive bond. NASA chemically treated the underside of the tiles to make them stronger, then reattached and tested them with a vacuum machine that pulled at each piece with a measured force. Still, on its April flight, Columbia lost all or part of at least 15 tiles from relatively uncritical areas on its orbital engine pods. The tiles were apparently loosened by a combination of engine vibration and aerodynamic shock shortly after launch. NASA is working on



Custom-made tile with I.D. numbers

modifications to ensure that even this minor loss will not happen again.

Will future shuttles be insulated in the same way as Columbia?

New tiles that are even lighter and stronger are planned for Challenger, scheduled for delivery in mid-1982. On the third shuttle, Discovery (1983), many of the tiles on the upper wings and fuselage may be replaced by fiberglass cloth stitched with quartz thread. Space skeptics, if any are left by then, can change their derisive nickname for the shuttle from the "Flying Brickyard" to the "Orbital Quilt."

—Monte Davis

At the Johnson Space Center, a technician checks tiles on a test mock-up



Tile just out of 2,000° oven



PHOTOGRAPHS BY JOE McNALLY

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cupping as much as five cubic feet. NASA has sold hundreds of these "get-away specials" to movie moguls, magazines, celebrities, schools, entrepreneurs, and just plain folks. One of the latter is Jerry Juska, an advertising manager for International Harvester, who plans to grow crystals in zero gravity. "This is a once in a lifetime opportunity to be a pioneer in something," he says. "I didn't live in the old West, where you could go out and stake your claim for gold. This is virtually the same thing, but it involves technology."

All this activity has spawned a whole new set of astronauts. While pilots like Crippen and Young take care of the spacecraft, crew members known as mission specialists will mind the space business—snagging satellites and launching them, space-walking and tending to scientific experiments. Working in Spacelab will be payload specialists: almost anybody in good health can qualify for that job. Shuttle operations should be so routine and tranquil, in fact, that these passengers will not even have space suits of their own; in emergencies they will be bundled into oxygen bags that look like large yellow beach balls and floated over to a rescue shuttle.

One customer for the space shuttle seems to be missing, and that is NASA itself. Although some spectaculars are still planned—the 1985 launch of both the space telescope and the Galileo orbiter and probe to Jupiter, and several scientific "sorties" with Spacelab—extra expenses for the shuttle and budget cuts over the past several years have eaten away at NASA's space science money. Thus there will be no mission to Halley's comet. Projects to orbit Venus with an imaging radar to see through its hot clouds, and to launch a gamma-ray observatory to study the most energetic radiation in the universe, have been delayed. NASA was recently forced to cancel its half of a joint U.S.-European project to send twin spacecraft over the poles of the sun—to NASA's chagrin and Europe's outrage.

"Frankly, the U.S. deep-space program is in jeopardy, and may even face extinction," said planetologist Bruce Murray, of the Jet Propulsion Laboratory, in testimony before a House subcommittee in March. "Despite its widespread popularity and national significance, this nation's unique capability to explore the solar system is fast eroding and approaching collapse." One reason, many scientists suggest, is a misplaced and wasteful emphasis on manned spaceflight, dom-



Ship recovers Columbia's booster rockets in the Atlantic

inated by military considerations. They suspect that NASA and the Air Force have taken them for a ride on the shuttle. Last year Air Force Secretary Hans Mark (recently nominated to be NASA deputy administrator) said regarding the shuttle, "NASA is in fact a minor user and not the driver. That's something the NASA folks don't like to hear, but it is true."

The military has been NASA's "silent partner" in the development of the space shuttle. The spacecraft's cargo bay and landing maneuverability were both increased to meet Air Force requirements. In turn, the Department of Defense has put its weight behind the shuttle program at critical times. The Air Force, which recently formed a new space division, is building its own shuttle launch and landing facilities at Vandenberg Air Force Base, in California, and a control center in Colorado.

About a third of the early shuttle flights have been booked by the military. Besides being used as a space truck, the shuttle might be effective in reconnaissance and, the Soviet press has charged, the destruction of Soviet satellites. Air Force officials deny that this is the case—yet. "Reality," explains Lieutenant General Richard Henry, space division commander, "dictates a more frugal and austere outlook. Let's say that the future holds many oppor-

tunities for those of us in the military arena."

Some of those opportunities will be tested on early shuttle flights. They include an infra-red sensing and tracking device called Teal Ruby, which could track aircraft over land and water. Another system, named Talon Gold, will use a laser to pinpoint and follow objects. Talon Gold could ultimately be used to aim a space-based laser that could zap other spaceships or satellites. NASA has its own plans for the future, dependent on a kind word or two from the White House. "Our next goal is the permanent occupancy of space," explains Ivan Bekey, advance planner at NASA headquarters in Washington, D.C. The key to that occupancy is a manned space station—the other half of the original space shuttle concept—that could be built by the end of the decade. NASA designers are debating two different ways to achieve that goal.

The first step, says Bekey, is to extend the length of time—now about a week—that the shuttle can stay in orbit. That limitation is due to the capacity of the fuel cells that supply the orbiter with power. "The shuttle is a good booster, but a lousy space station," says Bekey. The answer is to unfold solar panels from the cargo bay; the extra power would make the shuttle livable for up to a month.

The next step is to have free-floating arrays of solar panels, sort of like elec-

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trical outlets in orbit, at which the shuttle could leave instrument packages, or perhaps a Spacelab module, in space for an extended time. These orbiting outlets are called power utilization platforms. As more solar-cell arrays were added to a platform, it might slowly evolve into a space station, an idea proposed by engineers at the Marshall Space Flight Center, in Alabama.

At the Johnson Space Center, designer Clarke Covington and his colleagues have a different idea. They propose building a space station from scratch, out of materials brought up by the shuttle and assembled in orbit. Rather than being a scientific observation platform, this would be a space operations center (SOC). It would serve as a way-station between earth and deep space, staffed by a permanent crew. Much of the action in space, Bekey explains, would be to place large communications and other satellites in geosynchronous orbit, 22,330 miles up, where they would hover over the same place on the earth, making it easy to aim antennas at them. But because of its limited fuel capacity, the shuttle can fly to an altitude of only about 500 miles. For this reason, the shuttle's cargo would be off-loaded at the SOC and transferred to space tugs, which would take it out to a higher orbit. Bekey estimates that an SOC could be built by 1983 for about \$6 billion, and that by the year 2000 there could be a platform, either manned or unmanned, at the geostationary altitude.

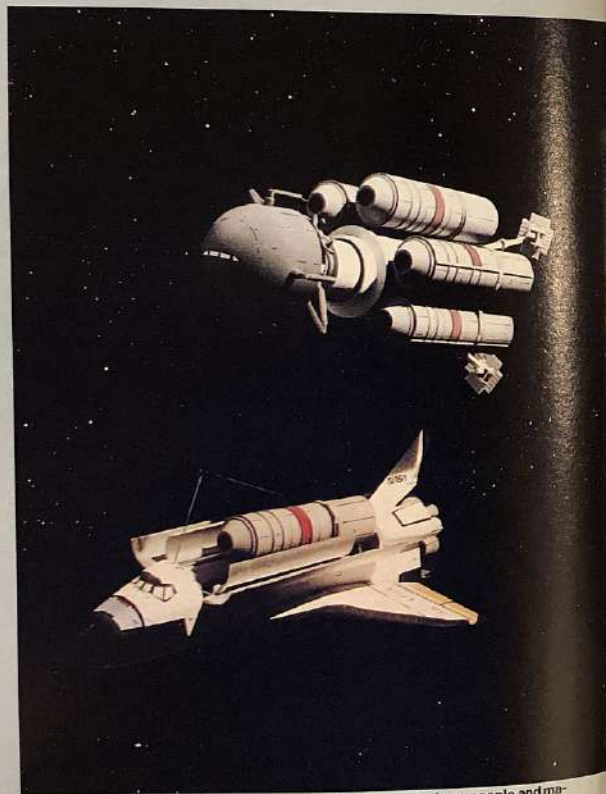
One of Bekey's favorite ideas is that of a very large communications satellite. The larger the antenna in space, he points out, the smaller the ground antenna needed to communicate with it. "You could build Comsats so big that everybody could have wrist radios," says Bekey. "These things are going to happen. The Orbital Hilton is coming, although it's nothing we're planning."

On earth, the orbital taxi, Columbia, its belly a little scratched and nicked, was back at the Kennedy Space Center. Inspectors now think the damage may have been done by ice or insulation flying off the huge external tank during the shuttle's ascent. After a week of intense de-briefing, Young and Crippen presented the next shuttle crew, Engle and Truly, with a key to the Columbia. With 500 flights projected by the end of the decade, such rituals could become a bit passé. Crippen had waited twelve years to go into space: "I'd wait another twelve years, but I don't think I'll have to wait so long the next time around."

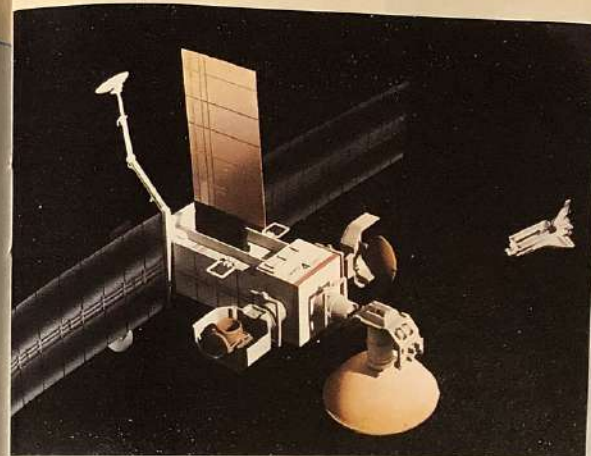
NASA's Visions of the Future

The scenes on the next three pages come not from a movie set but from the drawing boards at NASA. The space shuttle marks the beginning of a transition from exploring space to using it. NASA has begun to plot the next steps, and all that stands between its visions and reality is a little time and a lot of money.

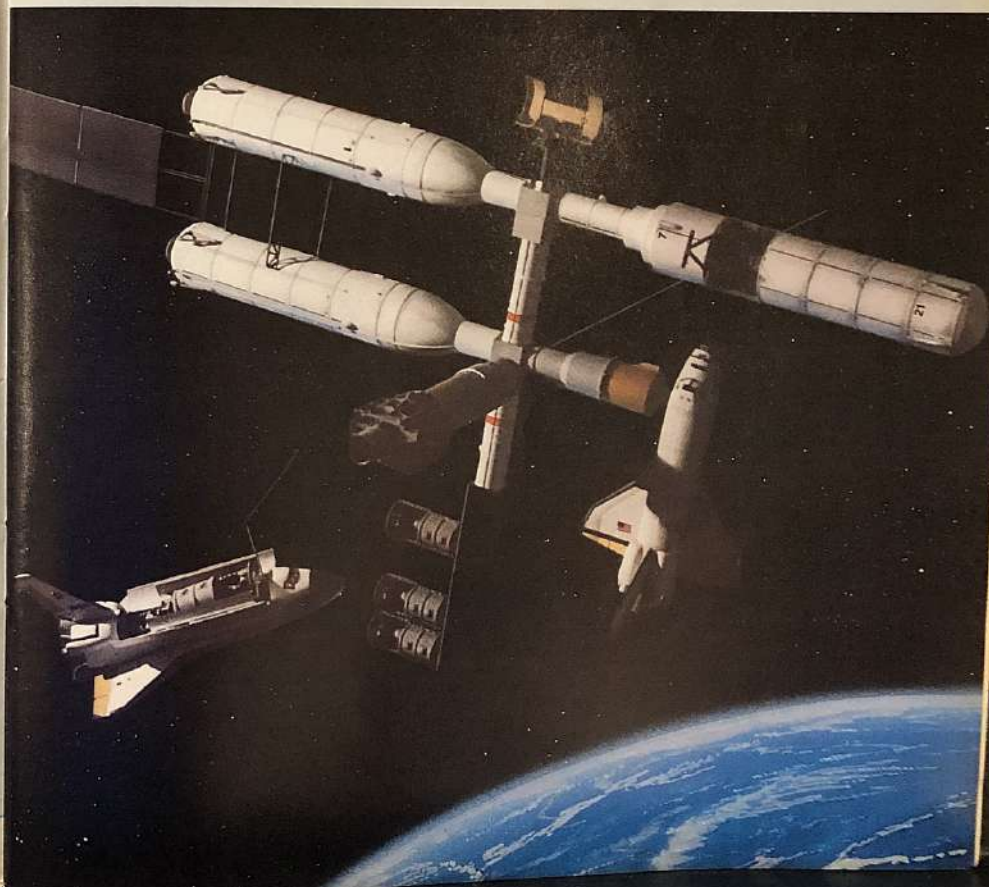
Models by Brian Sullivan



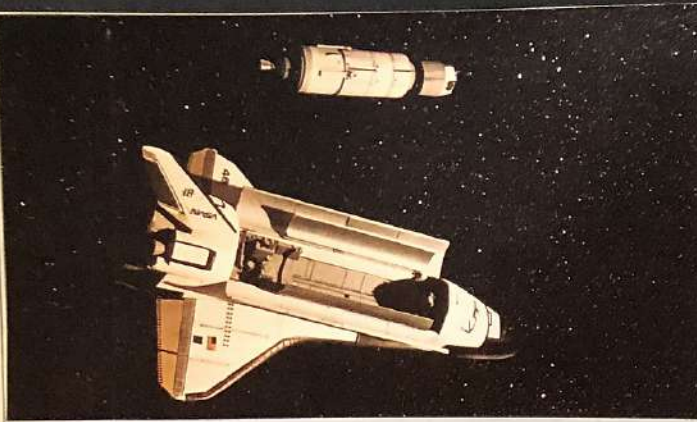
A shuttle designed to ferry people and materials to the moon is assembled from parts transported into orbit by shuttles. Emerging from the shuttle's cargo bay is one of the lunar transport's fuel tanks.



Power utilization platforms powered by solar panels could serve as orbiting stations for scientific experiments. Clusters of them could evolve into space stations.



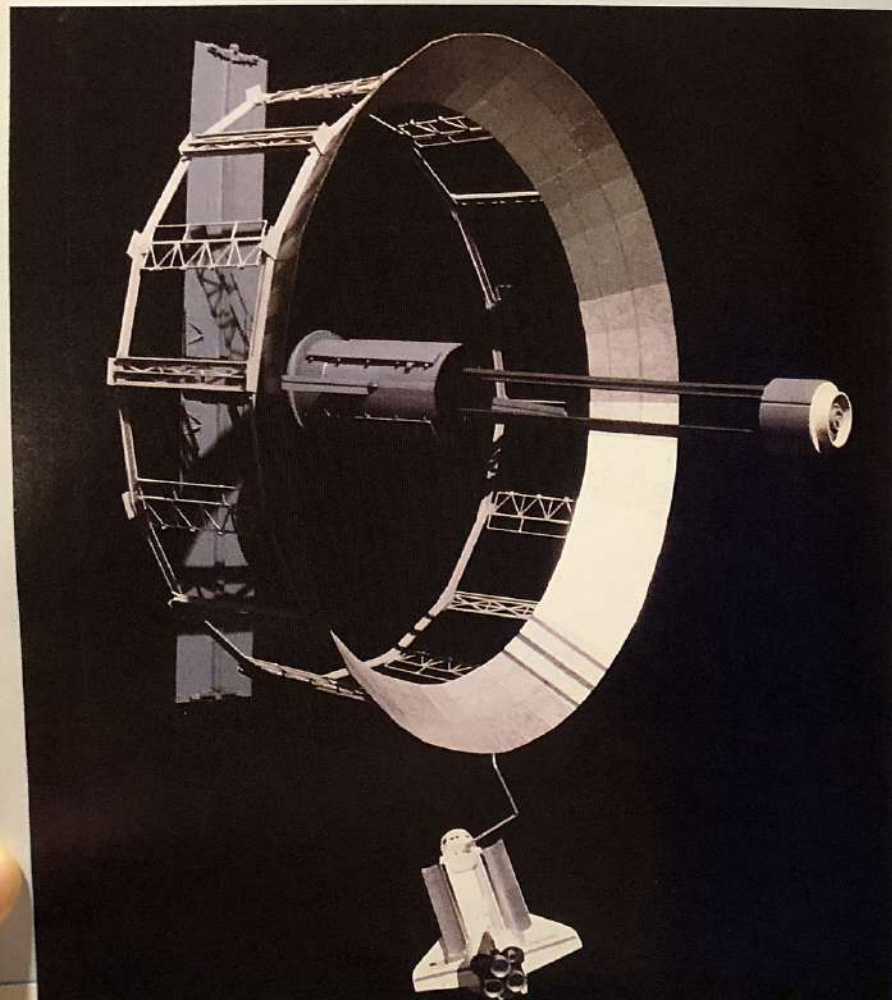
A shuttle carries supplies to a space operations center under construction. The center would serve as a way-station between earth and deep space. The large modules are external fuel tanks boosted to orbit and refurbished for occupancy.



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A deep-space probe is launched from the shuttle. After the two spacecraft have cleared each other, a booster rocket will start the probe on its long journey

A cottage among the stars. Work begins with the fabrication of the innermost section of a space settlement that will eventually consist of five concentric rings



FROM HERE TO SERENDIPITY.

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SCIENTIST OF THE YEAR

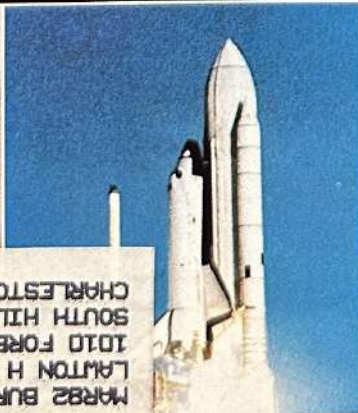
DISCOVER

THE NEWSMAGAZINE OF SCIENCE
JANUARY 1982

THE YEAR IN SCIENCE



ANIMAL TESTS



SHUTTLE FLIGHT



MEDFLY CRISIS

SATURN FLY-BY

SPACE

ONCE MORE INTO THE VOID

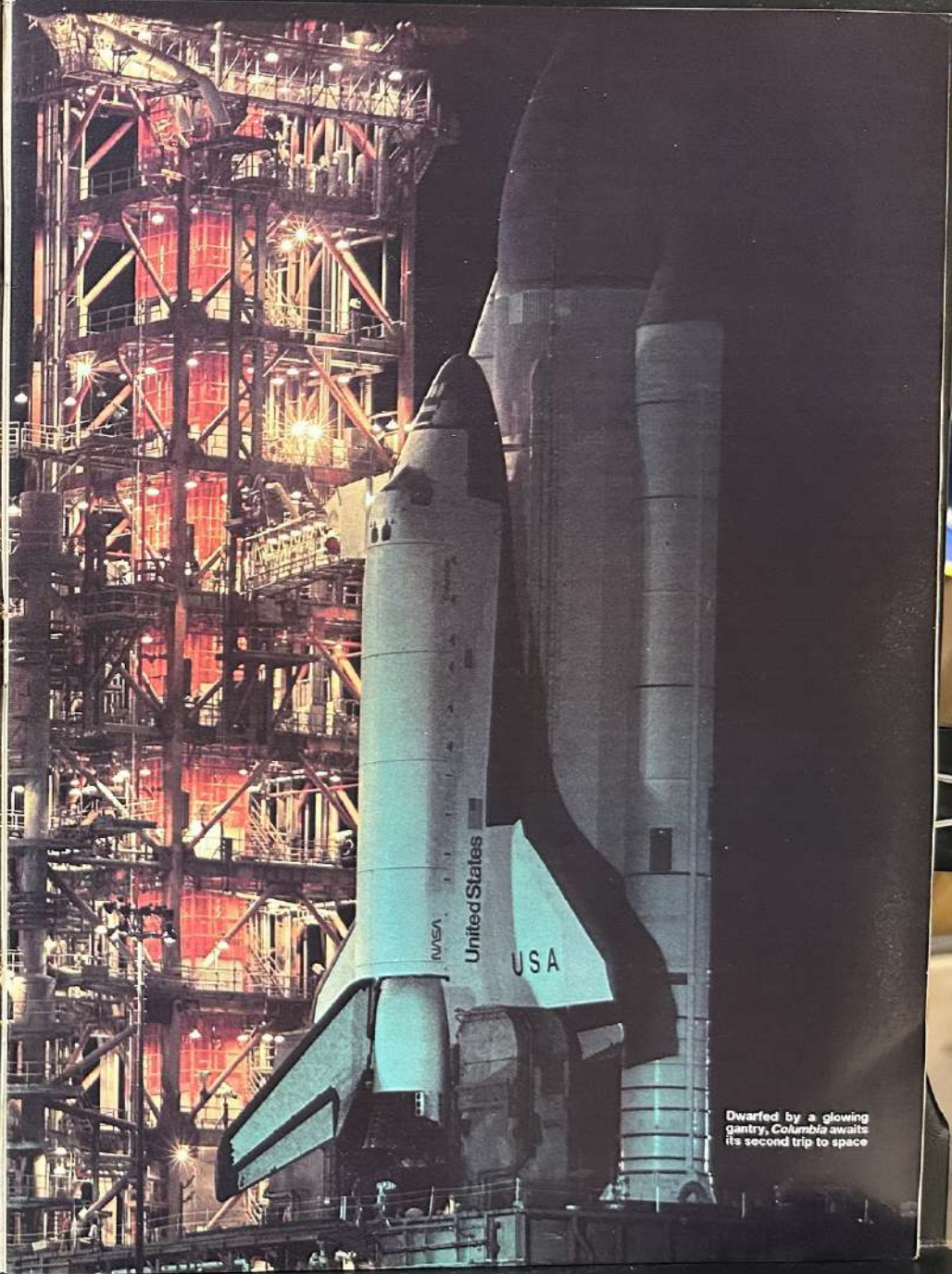
Despite delays and electrical problems that forced an early touchdown, the space shuttle makes a triumphant second voyage

by DENNIS OVERBYE



PHOTOGRAPH BY
JOE McNALLY

16



Dwarfed by a glowing gantry, Columbia awaits its second trip to space

It was just past midnight in eastern Australia, but to Joe Engle and Richard Truly, 137 miles overhead and flashing through time zones in the space shuttle *Columbia*, it was midmorning of their second day in orbit. Just getting the hang of working in zero gravity, the astronauts were dodging floating notebooks while they flexed the shuttle's new robot arm and photographed the cloud-dappled earth below. As the spacecraft hurtled beyond Australia and out over the Pacific Ocean, the astronauts heard a disquieting hint from Sally Ride, the capsule communicator at Mission Control in Houston. During *Columbia*'s upcoming pass over the United States, Ride said, they would discuss plans for the rest of the flight, originally scheduled for five and a half days. "Okay," replied Commander Engle, adding "Ready to keep going if you are." Responded Ride plaintively, "I was afraid you'd say that."

Ride already knew that NASA managers and the mission controllers, worried about the loss of one of the spacecraft's three electricity-producing fuel cells, had already decided to terminate the shuttle's glitch-ridden second flight three days early and bring the black-snouted bird back to earth the next day. Some 30 hours later, with the game but disappointed astronauts at the controls, *Columbia* blazed across the California coast 24 miles high at five and a half times the speed of sound and plummeted like a diving hawk through the desert sky. Escorted by mosquito-like chase jets, *Columbia* swung wide around Edwards Air Force Base and then touched lightly down on the dry lake bed, rolling in a cloud of dust straight down the dotted black line that marks runway 23. It was only the third time (and the first since the spine-tingling flight of Apollo 13) that an American manned space mission had come home early.

On the ground, after a ritual inspection of the spacecraft that included kicking the tires, Engle and Truly took turns exulting in their "magnificent flying machine." Despite their early retreat from space, the astronauts and NASA had a lot to brag about. The world's first reusable spacecraft had been successfully reused. Its new robot arm had worked superbly, and the shuttle's first scientific payload—a battery of earth-resources sensors—had returned with enough data to keep scientists busy for a year. In fact, mission controllers insisted *Columbia*'s second flight had achieved 90 per cent of its

Columbia heads for space

DISCOVER / JANUARY 1982



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original goals. All that without losing a single tile, though a dozen or so were damaged.

But these triumphs were tempered by a plague of failures and glitches, rekindling fears that small technical failures in the sophisticated shuttle system could nickel-and-dime it to death. *Columbia* flies, but the NASA vision of airline-type operations that would return the complex vehicle to space every two weeks now seems as distant and tenuous as the rings of Saturn. Said launch director George Page, "I can't imagine going through all this every two weeks. If we get to eight weeks, I'll be tired."

The shuttle's second lift-off, on November 12, came half a year after its first two-and-a-half-day venture into space last April. But that was one month, eight days, and two and a half hours late. NASA officials had hoped to complete refurbishing and assembling the spacecraft, including replacing some 1,500 damaged or missing thermal tiles, in time for an early October launch. But disasters, large and small, slowed them down. While *Columbia* was in Kennedy Space Center's Orbiter Processing Facility, a forklift ran into it, damaging a few more of the fragile tiles. Then in September, while the orbiter's fuel tanks were being filled with hydrazine, a quick-disconnect valve disconnected, spilling several gallons of the corrosive liquid down the side of the spacecraft; loosened tiles fell like autumn leaves, and *Columbia*'s



Bespectacled Truly chases teleprinter copy through zero gravity

launch was delayed until November.

When astronauts Joe Engle, 49, and Richard Truly, 43, and a suitcase full of dwarf-sunflower seeds (for zero-gravity growing experiments) were tucked into the cabin on the morning of November 4, gathering storm clouds appeared to be the only threat to *Columbia*'s launch (the astronauts need good visibility in case they have to abort the launch short of orbit and glide back to Cape Canaveral). During the countdown, however, launch officials noticed that the pressure in the three liquid-oxygen tanks that supply *Columbia*'s fuel cells was near the lower limit allowed by Launch Control's fussy computers, although it

was adequate for the flight. As the clock counted down to 31 seconds before launch—at which point the ground computer gives the final go and begins handing control over to computers aboard the shuttle—technicians realized that the pressure had fallen below the lower limit and frantically tried to order the computer to ignore it. But they were too late, and the countdown was halted.

By then, controllers had noticed another problem in the ship's auxiliary power units, which burn hydrazine to supply hydraulic power to the shuttle's control surfaces and swivel its main engines. Without these units, *Columbia* cannot be maneuvered in the atmosphere, and the oil pressure in two of them was abnormally high. Engineers deduced (correctly, as it turned out) that waxy contaminants had clogged the units' oil filters, and although everyone believed that the power units would work anyway, NASA decided to play it safe and scrub the launch.

The next countdown, a week later, did not begin any more auspiciously. An electronic device called a multiplexer-demultiplexer, one of many that combine and encode data from flight instruments for transmission to the ground, failed on the day before launch. Its replacement also failed. The cupboard bare, space officials hastily cannibalized the second shuttle, *Challenger*, under construction in California, and sent two of the boxes to Florida. One was finally installed and working at midnight of launch eve.

November 12, Richard Truly's 44th birthday, dawned clear and cloudless. Falcons riding the thermal updrafts near the giant Vehicle Assembly Building swirled over the launch site, the

NASA crews, and the silent machine below. The astronauts' traditional breakfast was supplemented with a multi-candied birthday cake, and Kennedy Space Center director Dick Smith promised to light one more candle, the larger one outside.

Finally, ten minutes after its rescheduled take-off time, with a squirt of yellow flame and a sudden billow of smoke, *Columbia* awakened at last. It rose, turning, through a small cloud and arched eastward on a towering, smoky pillar. The shuttle was still in sight two minutes later, 18 miles high, when it jettisoned its twin solid-fuel boosters, and for several minutes thereafter as its main engines burned toward orbit—a small star streaking back to space, eager to leave its earthly problems. Reported Truly, "You wouldn't believe this. This is fun."

Unfortunately, the gremlins were not far behind. *Columbia* was in its second orbit when they struck one of its three fuel cells, which use hydrogen and oxygen to produce water and electricity for the spacecraft (see box, page 22). A device measuring acidity indicated that one cell had flooded and was washing out its alkaline electrolyte and liquid water along with water vapor and hydrogen.

Not only would potassium hydroxide in the drinking water be unpleasant, but liquid water in the manifold around the cell would be exposed to 28 volts—enough to split the water molecules into a potentially explosive mixture of hydrogen and oxygen gases. When the cell began losing voltage, five hours into the flight, the controllers ordered it shut down.

Although the spacecraft could operate normally on only two fuel cells, and manage to return safely to earth with only one, NASA felt its security blanket was wearing thin. The mission directors began to consider bringing *Columbia* down early, before another failure could cause serious trouble. They put into effect an abbreviated flight-activities plan, called the minimum mission. This was to ensure that the most important chores of the mission, especially the tests of the new robot arm, were accomplished on Day Two. Thursday night, backup astronauts Ken Mattingly and Henry Hartsfield practiced reentries in the shuttle simulator with one or two fuel cells working. In the morning the decision, cleared all the way through NASA administrator James Beggs, was announced: *Columbia* would leave orbit on Saturday.

One of Houston's highest priorities

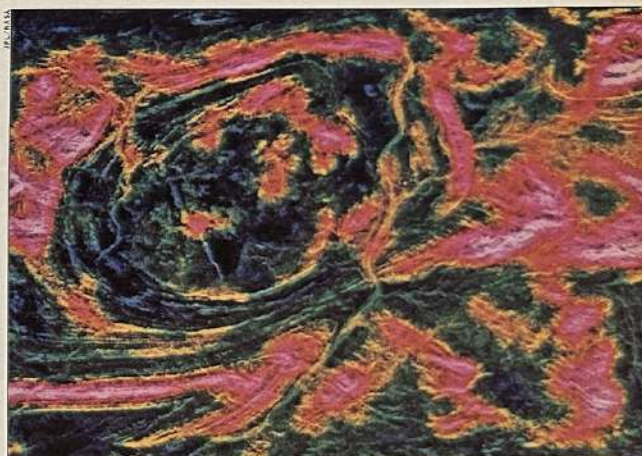
was to record flight data during dozens of small aerodynamic maneuvers that Engle and Truly were to put *Columbia* through during its fiery re-entry. On the first flight, the tape recorder had jammed and no re-entry data had been obtained. If another fuel cell failed, there would not be enough electric power to run the recorder. Moreover, after the weekend, Pacific storms would move across Edwards Air Force Base, the primary landing site for the shuttle. There was reason enough to order a Saturday landing.

"It's the prudent thing to do at this point in our test program," said Johnson Space Center director Christopher Kraft, although he later conceded that if this had been an operational flight, *Columbia* would probably have stayed up.

It fell to Ride, one of eight women as-

ing of its \$100 million remote manipulator system (RMS), a gift of the Canadian government, which built and delivered it. The 50-foot arm, complete with shoulder, elbow, and wrist joints, is mounted behind the cabin on one side of the vast payload bay. Using a wire grapple on its end, astronauts inside the shuttle will be able to move payloads around in the bay, and retrieve and launch satellites. Television cameras on the wrist and elbow of the RMS will permit astronauts to inspect the outside of the shuttle, including its underside. This was the first real test of the arm, which is too frail to support its own weight on earth. The astronauts did no heavy lifting, but merely unlatched the spindly limb and flexed it to make certain it was working properly.

Hanging outside the shuttle, the remote arm looked like a gigantic sky-



Radar image of Australia's Hammersley Mountains codes terrain types in colors

tronaunts in training and the first female voice to crackle across American space channels, to tell Engle and Truly the bad news. A poor radio connection forced her to repeat the message. "Oh, okay," responded Engle at last. "That's not so good."

Said Ride, "Think of it [this way]—that you got all of that good... data and you just did too good a job; we're going to bring you in early."

Indeed, the premature return almost overshadowed the high point of *Columbia*'s brief stay in orbit—the unlumber-

hook. The arm's television cameras treated the astronauts and the television audience to spectacular views of the payload bay and shuttle, including a shot of the crew compartment with an astronaut holding up to the window a sign saying "Hi, Mom." In its initial outing, the arm proved virtually flawless. "We're ecstatic," said a Canadian spokesman, as he handed out cigars in Houston.

The presence of Ride, a former junior tennis star, magazine editor, and x-ray astronomer, at one end of the Houston-

Astronauts put the new remote manipulator system through its paces



SPACE

outweighed the agony of coming back early. "You wouldn't believe some of the things we saw," declared Engle. Said Truly, "You can spread the word around, we got a good one." Overlooked in the excitement was the fact that *Columbia's* second test had originally been planned for only three and one-half days but was lengthened after the shuttle's flawless maiden flight. Engle and Truly were only a day short of the original schedule.

Still, the dust had barely settled on the runway before the space agency's critics blew up their own storm. Pointing to the long turnaround and the delays, a spokesman for the right-wing Heritage Foundation argued that the shuttle might never be as economical as the old expendable rockets, and that NASA should consider abandoning it. Senator William Proxmire contended that the sophisticated shuttle was a waste of money that had sapped the vitality of the rest of the space program.

Nonetheless, NASA, Defense Department, and White House officials have made it clear that the shuttle does have a future. Not the least indication was the visit of the nation's number one space cadet, Ronald Reagan, to Mission Control on Friday evening for a stint as honorary capcom—"a rare experience for an old horse-cavalry officer." On the morning of their return to Houston, the astronauts breakfasted with Vice President George Bush.

Even so, NASA, already the subject of a long-range study by White House science adviser George Keyworth, is doing its own looking down the road. A recent memorandum circulated by deputy administrator Hans Mark to center directors outlined some of the issues for the years ahead. The main thing on NASA's agenda is getting presidential approval within the next two years for a permanent space station—a space operations center (DISCOVER, June). NASA is also considering eventually

transferring shuttle operations to a separate government organization or a private one, and moving Mission Control with its simulators and perhaps the astronaut office to the Kennedy Space Center in Florida. Mark's memorandum foresaw an increasing emphasis on military space applications and suggested that planetary exploration would take a back seat to orbiting experiments until deep-space probes could be assembled in orbit. NASA, he revealed, is also studying the clustering of shuttle solid-fuel rockets to make unmanned launch vehicles.

Some of those prospects are open to debate, as Mark points out, but the plans for *Columbia* are a little firmer. It touched down in better shape than after its first mission; only six tiles had lost their surface and a few more were chipped. The launch pad was also in better shape, probably because a 100,000-gallon-a-minute water spray was used to damp shock waves from the

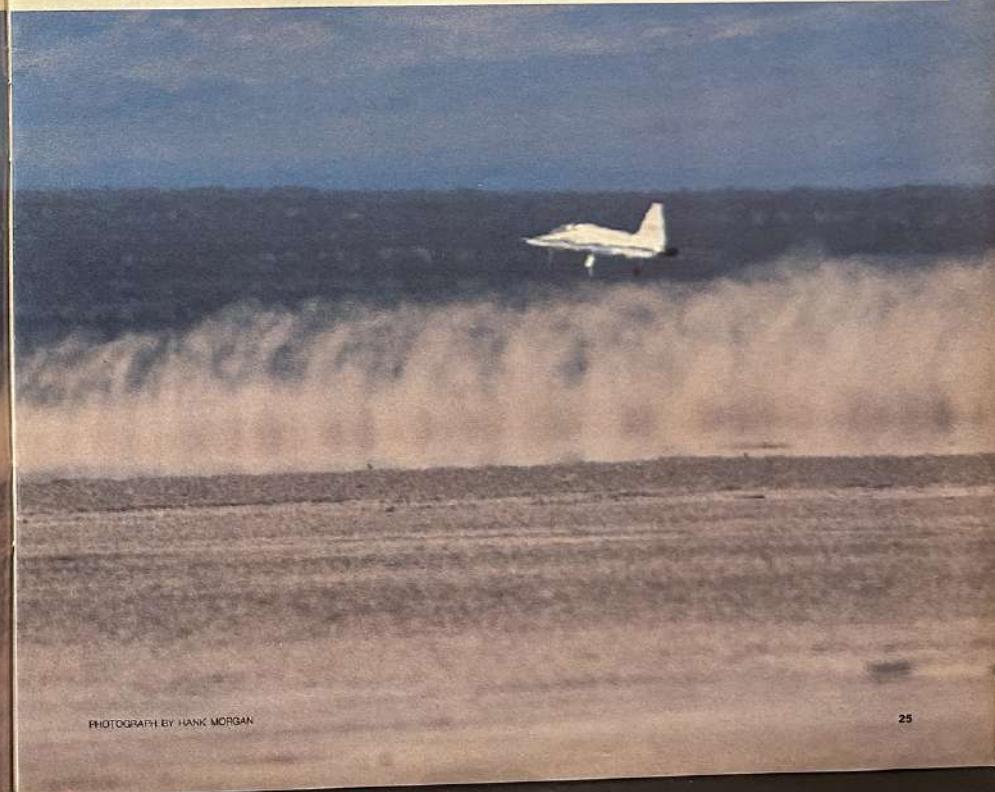
powerful solid boosters during lift-off.

In March, NASA hopes to launch *Columbia* on its third flight, a mission now planned for seven days. Next time *Columbia* will take off and re-enter at steeper angles and higher speeds, which will subject it to more aerodynamic stress. The arm will grab a special detector out of the bay and move it around the spacecraft so it can sniff for shuttle-generated gases that could interfere with delicate scientific experiments. If all goes well, the fourth and last test flight will occur next July.

A year ago all but the staunchest space buffs would have scoffed at a prediction that by November 1981 *Columbia* would have been to space and back twice, and that the second mission would have been completed with barely a mention of the infamous thermal tiles. But this is exactly what has happened. And it is perhaps the most hopeful sign that more Americans will soon have a chance to get the hang of zero gravity. □



Above: black-bellied *Columbia* glides toward home. Below: touchdown at Edwards



PHOTOGRAPH BY HANK MORGAN



THE YEAR IN SCIENCE

In the year gone by, the eyes and minds of scientists pressed man's attack on the secrets of nature, probing the smallest building blocks of matter while scanning the boundless sweep of the cosmos. There were some missteps and failures, but there were also successes and moments of high adventure that will be long remembered.

The dazzling photographs of Saturn transmitted almost a billion miles to earth by Voyager 2 capped a decade of planetary discovery unequalled in history, and the epochal maiden flight of the space shuttle brought man a long step closer to making himself at home in the extraterrestrial void.

To explore the most minute regions of inner space, scientists were completing gigantic machines that force beams of nuclear particles into violent collision with beams of antimatter; the first machine, to the envy of Americans, began operation during the year in Europe, and it is expected to yield great discoveries.

Medicine continued its battle against disease and ageing, winning no big victories but making progress on a number of fronts and helping to improve the quality of life. Medical researchers also made strides in deciphering the complex processes of life, striving for a deeper understanding that could lead to the conquest of cancer and other major diseases.

It was a good year for American science in particular. Of the eight winners of the three Nobel science prizes, six were Americans. But U.S. dominance of science is seriously threatened. The faltering national economy brought sharp reductions in the proposed federal budget for science. As a result, U.S. planetary exploration will come to a virtual halt, and the world's most talented team of space scientists, painstakingly trained and assembled over more than a decade, will be largely dismantled. The ruthless slash in federal money for research in high-energy physics led the Nobel laureate physicist Sheldon Glashow to the gloomy conclusion that 1981 "seems to mark the termination of American efforts in the field."

Perhaps worst of all are the long-range effects of the possible reductions. Among the year's budget cuts was one that practically eliminated the important role of the National Science Foundation in supporting education. Years of education and training are needed to produce good scientists, and much of the best American science has come from campus laboratories. The time may come when few or no Americans travel to Stockholm to pick up Nobel medals.

Still, despite their problems, scientists performed remarkably well in 1981, as the following pages recall.

A Voyager 2 photograph of Saturn

October 1980

PREMIER ISSUE

DISCOVER

THE NEWSMAGAZINE OF SCIENCE

COMPUTERS AS ARTISTS

HURRICANE!

BRAIN SCANS FOR
MENTAL ILLNESS

AUTOS THAT THINK

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by a computer

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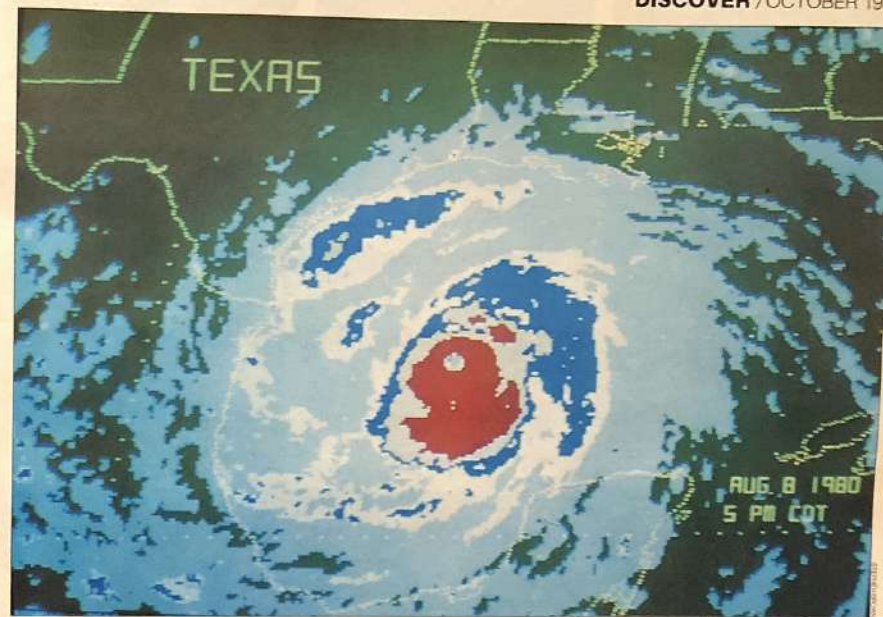
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DISCOVER / OCTOBER 1980



METEOROLOGY

HURRICANE!

by BRUCE SCHECTER

The dramatic satellite photograph above shows Hurricane Allen 48 hours before it crashed across the Texas coast. A computer has rendered the storm's fury in color: red indicates the colder areas found in the center of a mature hurricane; blue swirls show the wind vortex; green and brown indicate the cooler land and sea areas.

Allen, which was one of the mightiest storms ever to cross the Caribbean Sea, providentially spared Texas. Though it destroyed \$600 million worth of property, only four people were killed there.

But in its merciful wake, Allen sowed the seeds of complacency.

That could be dangerous. Hurricanes kill hundreds of people, sometimes thousands, every year. Knowledge of these murderous storms is still scanty; perhaps some day they can be controlled. Until that time, there is po-

tential for disaster along the overcrowded Gulf and Atlantic coasts; experts fear that a big hurricane could kill 60,000 Americans. The following is the story of Allen, the storm that nearly turned that fear into terrible reality.





Allen's progress: Saturday, 1 p.m.



Saturday, 6 p.m.



Sunday, 1 a.m.

The telephones kept ringing at the National Hurricane Center in Miami. They made a gentle chattering sound that belied the urgency of their demand. Hurricane Allen, the second most violent storm ever to cross the Caribbean, had entered the Gulf of Mexico. In a few hours, a day at the most—there was no way to know for certain—it would crash across the Texas coast somewhere between Brownsville and Galveston, bringing raging winds, rain and a moving wall of water called the storm surge. What the callers wanted to learn was *When? Where? How bad? What the NHC fore-*

casters offered in the laconic drivel of airline pilots was educated guesses. Forecasting is not an exact science; hurricanes have minds of their own.

For the past week, ever since the tropical storm Allen had officially been upgraded to a full-fledged hurricane, it had been gaining force, threading a deadly course westward past Barbados, through the Caribbean Sea, past Haiti, Jamaica, and Cuba, through the Yucatan straits and into the Gulf of Mexico. Allen was a Five on the scale that meteorologists use to gauge hurricane intensity—there are no Sixes. Winds of

185 miles an hour had been measured at the core, and one airplane that flew into Allen's midst reported the second lowest central pressure ever measured in a hurricane. Central pressure is the truest measure of the strength of a storm; a hole had been gouged out of the atmosphere, and the surrounding air had shouldered its way violently into the center.

Considering its severity, Allen had done little damage, sidestepping at the last second whenever the potential for major destruction lay ahead. It largely spared Jamaica and Cuba. It narrowly missed the tourist resorts that dot the



Sunday, 7 a.m.



Sunday, 12 noon



Sunday, 6 p.m.

Yucatan peninsula. Still, the storm was less than a week old and it had already killed 272 islanders and several oil riggers on offshore platforms. Allen sat in the Gulf, spinning its winds, gathering strength for its assault on the U.S.

On half a dozen television monitors scattered about the Hurricane Center, Allen could be glimpsed as it appeared from the vantage point of a weather satellite 22,000 miles above the earth. Swirls and patches of clouds blanketed the entire hemisphere, but there was nothing anywhere like Allen; it filled the entire Gulf, nearly touching the shore on all sides. The televisions showed a

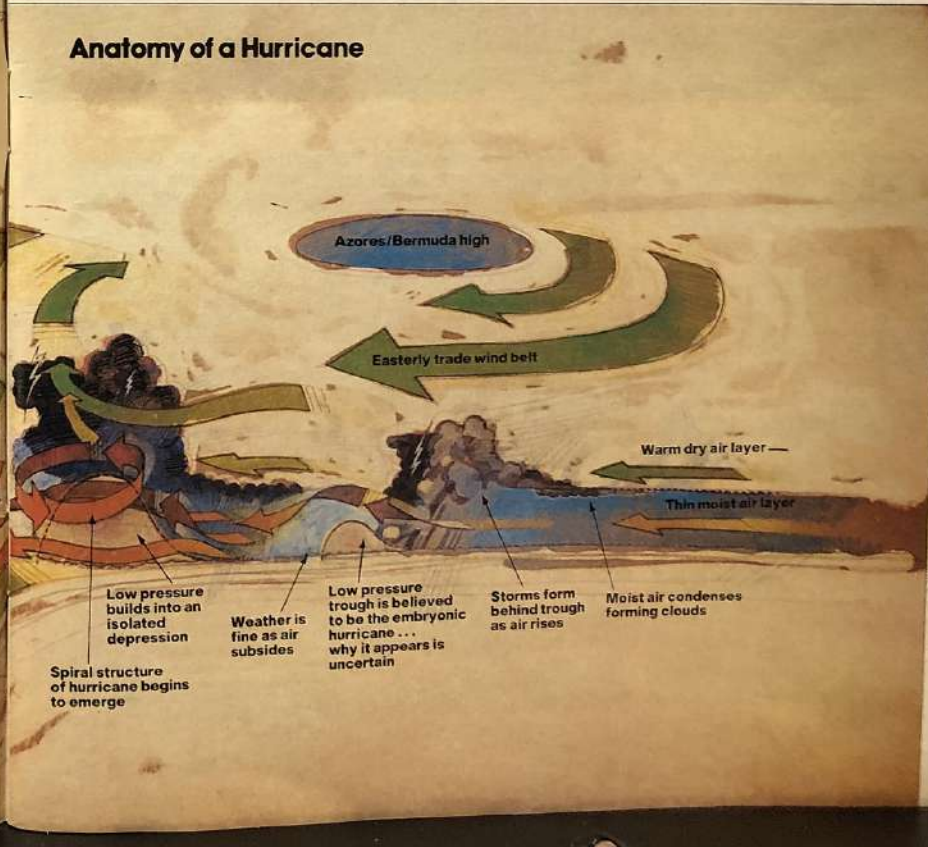
time-lapse film that compressed the last 12 hours of Allen's history into about five seconds. Then the film repeated in a slow, regular pulse. Allen spun, moving over and over again along its westward tack, always stopping just short of the coast, seeming to rehearse its landfall like a karate master practicing a blow that would smash a stack of bricks.

At 11 a.m. on Saturday, NHC director Neil Frank issued the official storm warning—his best guess. He called the conjectured track the "course of least regret." The warning covered 400 miles of the Texas Gulf Coast, placing the

storm's projected landfall slightly to the north of Corpus Christi. Residents were told to expect a storm surge of from 10 feet to 20 feet accompanying Allen's landfall. The storm surge is the deadliest part of a hurricane. The relentless winds blowing across hundreds of miles of ocean pile up wave upon breaking wave into a huge wall of water that inundates all low-lying communities. Added to this is the mound of water that the hurricane sucks up into its low-pressure center. In Allen, this mound rose up three feet above the sea surface before it invaded coastal areas. In 1900 a hurricane hit Galveston—the winds



Anatomy of a Hurricane





MARK FOLEY/STON



MARK FOLEY/STON



DAVID CORFIELD/CAMMA LUBSON



MARK FOLEY/STON

were only 120 miles an hour, but this was enough to generate a storm surge of 15 feet above the usual two-foot tide. Over this surge rode hurricane waves of 25 feet. The city of Galveston was demolished; over 5,000 people were drowned. It was the single worst disaster in United States history.

As Allen drew nearer, a piece of plywood to protect a house or a shop window could not be had for love or money in all of Corpus Christi. Only five strippers came to work at the Neptune Saloon downtown. Bob Choate, the owner, could relax and watch the strip show. "I don't have to board up," he explained. "No windows." Elsewhere along the Texas coast, there were other whiffs of the macabre. People held hurricane parties, waiting, with foolish bravado, for Allen.

The hurricane's origin is mysterious, part of a silent meteorological conspiracy that must be reconstructed from the most tenuous evidence. The clues all point to Africa, before the wind that would become Allen had a name. It was then an almost indistinguishable part of the global air flow, a kink in the prevailing, westward-marching trade winds that impinge upon the mountains of eastern Africa.

When the wind climbs these slopes it forms what meteorologists call an easterly wave, a ripple in the wind direction embedded in deep air currents; it is named for the direction of its origin, not its flow. Warm dry air from the African continent slides out over the Atlantic, and like the lid on a pot, settles over the soggy air below, trapping it. This moisture-laden air carries with it a powerful charge of energy in the form of latent heat—a kind of energy tax that water must collect from the sun in order to become vapor.

As the easterly wave wriggles its way west, the clashing winds are forced upward, drawing the moist surface air up with them. The moist air cools and condenses, releasing its store of heat. This heat warms the surrounding air, which also rises. A hole is being carved in the atmosphere, and that hole must be filled by intruding air. This air too is warm and heavy with moisture; it too rises, forming clouds and releasing heat—and the process intensifies. Still, the winds are relatively calm. Several other ingredients are needed for this tempest in a teapot to become threatening enough to earn a name.

Meteorologists do not fully understand the nature of these missing ingredients.

They know that the easterly wave appears frequently during the warm summer months and that most hurricanes are born over waters that are at least 79 degrees Fahrenheit.

What finally sets things spinning is the Coriolis force,* the effect of the earth's rotation on the wind. The Coriolis force bends the winds converging upon the center of the developing low into a vast, counterclockwise spiral. The spiral tightens and a delicate balance is reached; the wind can go no farther toward the center, but instead must swap inward motion for upward, rising in a large, vertical corkscrew. The rise is marked by a cylindrical wall of clouds, a vast chimney that in the mature storm can tower 50,000 feet over the sea. At this point, a contrary high-altitude wind crossing the top of the chimney could rip the maturing hurricane to pieces. Nine out of ten disturbances in the easterly wave, in fact, are aborted in this fashion.

But on this Friday, off the African shore, no contrary wind arrived to challenge the building storm. A breeze

*Named for Gaspard Gustave de Coriolis (1792-1842), the French civil engineer and physicist who first calculated the effect of the earth's motion on the moving atmosphere.

swept past the top of the central chimney and carried away the exhausted air in the middle as if it were drawing smoke up a flue; without this refreshing wind the inner depression would have filled up and the storm would have died. But, as air flew up the chimney, the central pressure dropped, and the winds intensified, building to speeds of more than 74 miles an hour. This was Hurricane Allen.

It was tremendous: hurricane-force winds as high as 185 m.p.h. pounded across thousands of square miles of ocean; beyond, in an area ten times as large, gale-force winds reached 63 miles an hour. In a single day the energy released by the storm equaled the amount unleashed by the detonation of 400 20-megaton hydrogen bombs.

For a full week this orchestrated mass, carried along by the trade winds, raced along a northwest track. Ahead of the storm, the ocean churned into frothy billows; within the hurricane eye, low air pressure sucked up sea water like a soda straw; this mound of water rose three feet above sea level. Almost as if it were navigating deliberately, Allen threaded its way through the Caribbean islands and into the Gulf

of Mexico. On Sunday, eight days after Allen had formed in the Atlantic, its eye crossed the Texas seacoast between Corpus Christi and Brownsville.

By Monday the worst was over. Allen, which had earlier been trumpeted as the hurricane of the century, was showing signs of fatigue. It was pinned for hours in the Gulf by a large high-pressure system hovering in the southeast. The outer arms of the hurricane were now stretched over land, and Allen was denied access to the warm moist air it needed for fuel. The friction between wind and land is much greater than that between wind and water, and this effect further eroded the hurricane's strength, reducing its force from a Five to a Three. That was still dangerous enough to bring havoc if the track ran over low-lying, populous land.

Yet again Allen was merciful. True to form, it found the path of least regret. The strongest winds and storm surge passed over the largely uninhabited Padre Island National Seashore. Said Gil Clark, an NHC meteorologist: "If you had to pick an area for it to hit, this was the best place."

The damage was bad enough. Police in Corpus Christi found the bodies of a 52-year-old man and a 63-year-old woman

who had drowned with her dog. Allen spawned tornadoes in south-central Texas. One injured about 20 people. Another destroyed three hangars and 60 airplanes at the Austin airport; damage was estimated at \$50 million. There was flash-flooding, and power failures hoppedscotched across the Gulf towns. Most residents of Mustang Island, off Corpus Christi, had headed for safer turf; the seawall that they had erected to ward off hurricanes was totally destroyed.

As its winds dropped below 74 m.p.h., Allen was downgraded to a tropical depression. In Miami the NHC's Neil Frank studied the latest satellite photo in disbelief. "It looks like a hurricane with eyes. Every time it was headed for some major destruction it wobbled away." Why? "Don't know and never will. But it always wobbled at just the right time."

Allen was perhaps just a warning, an indication of the arbitrary fury of nature. Frank and his colleagues have been trying for years to get the message across: people have been mindlessly building up the Atlantic and Gulf coast. Some day, inevitably, there will

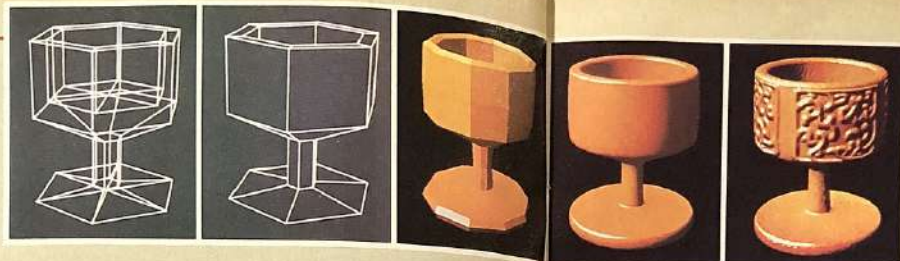
Gallery

THE COMPUTER AS ARTIST

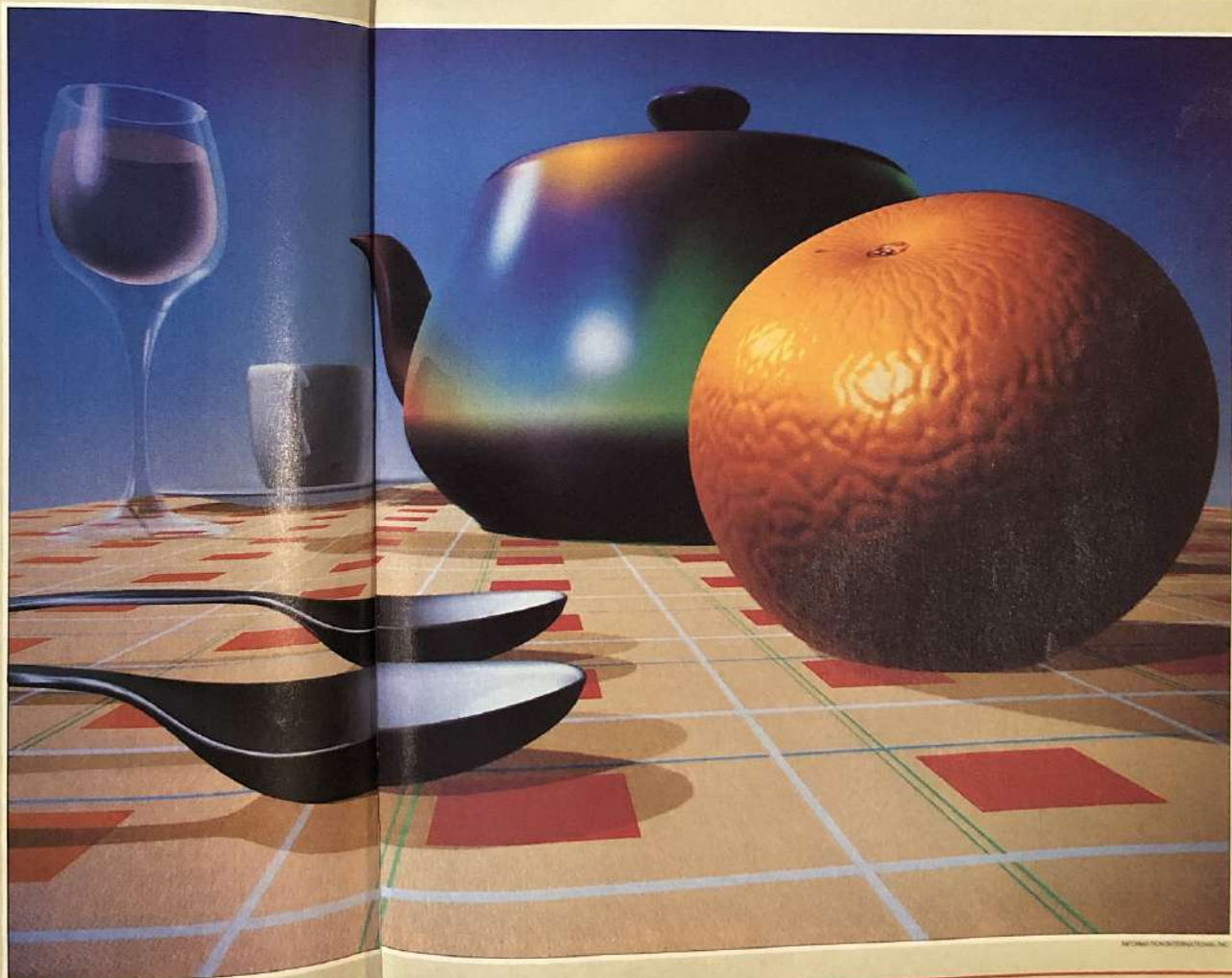
The work is reminiscent of the style of Magritte, and seems to portray an ant's-eye view of the world. Yet there is something even more surreal about the still life at the right—as well as the pictures on the next four pages and on the cover of this issue: the artist, in each case, is a computer. Creating art on a computer is no easy task (computers prefer Pascal's numbers to Picasso's nuances), and it takes someone with the mind of a mathematician and the eye of an artist to succeed.

In the computer world, these Renaissance men are called graphicists. They must convert the qualities that make an object look real—the transparency of a champagne glass, the shadows of spoons on a table—into the algebraic and geometric formulas that define them. The computer can understand these formulas, and can translate them into an image. Only the bare bones of that image, the vantage point of a viewer, and an imaginary light source need be specified. The computer does the rest, calculating intensity and color values for each of the million or so points on the screen.

Still, the graphicists have much to learn. They have taught computers to simulate surfaces like ceramic and metal, but are having trouble breaking down fur, hair, and smoke into tidy equations. Even with its mathematically perfect highlights and shadows, most computer art is not of ideal photographic quality. What is missing? Perhaps the computer is too precise, too literal. Seeking the answer, graphicists slip into the realms of the psychology and physiology of vision, hoping some day to impart to the computer the elusive qualities that make a great artist great.



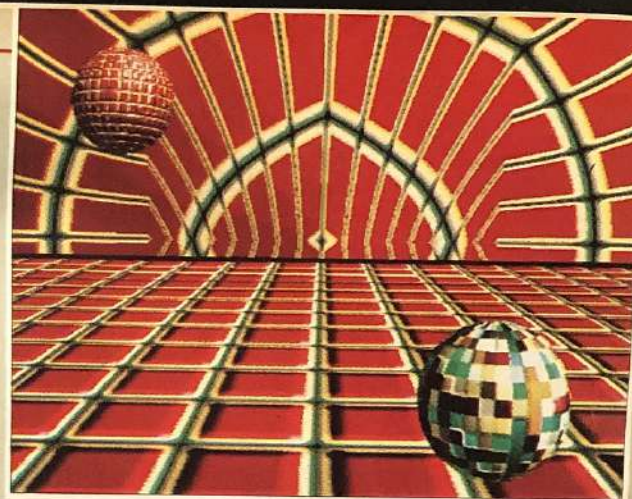
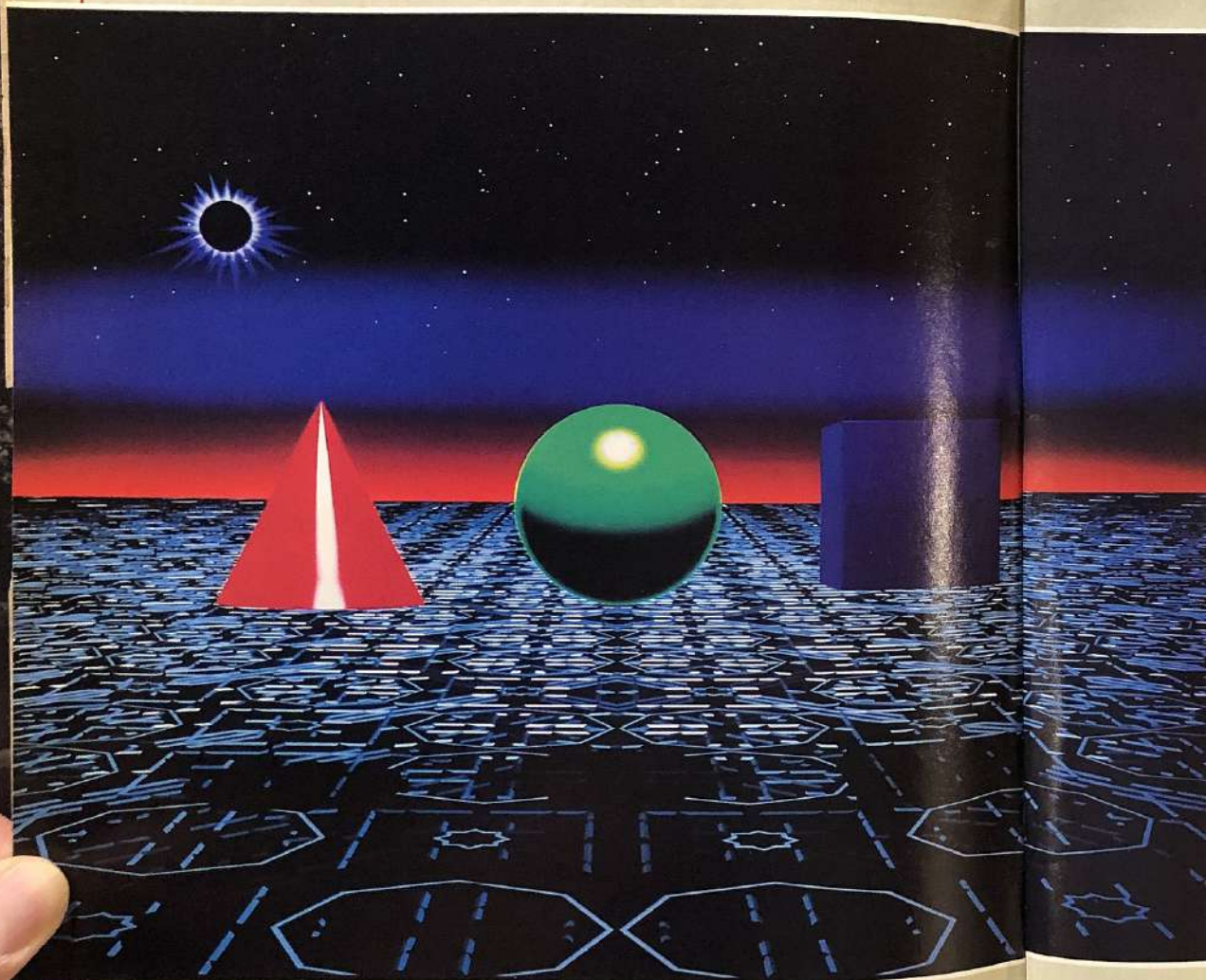
This sequence traces the evolution of the computer-generated chalice. 1962: The computer drew some 100 polygons from specified coordinates. 1967: Hidden lines were removed. 1969: Each polygon was colored according to its reflected light. 1975: New algorithms described the cup as a curved surface. 1980: After contemplating a pattern drawn on an electronic tablet, the computer designs a ceramic texture.



REYNALD FORTIN/REYNALD FORTIN, INC.

Gallery

The 72 million calculations needed for this picture taxed the Information International computer, but the firm hopes to convince Hollywood that scenes still created with props can be better done by computer graphics.



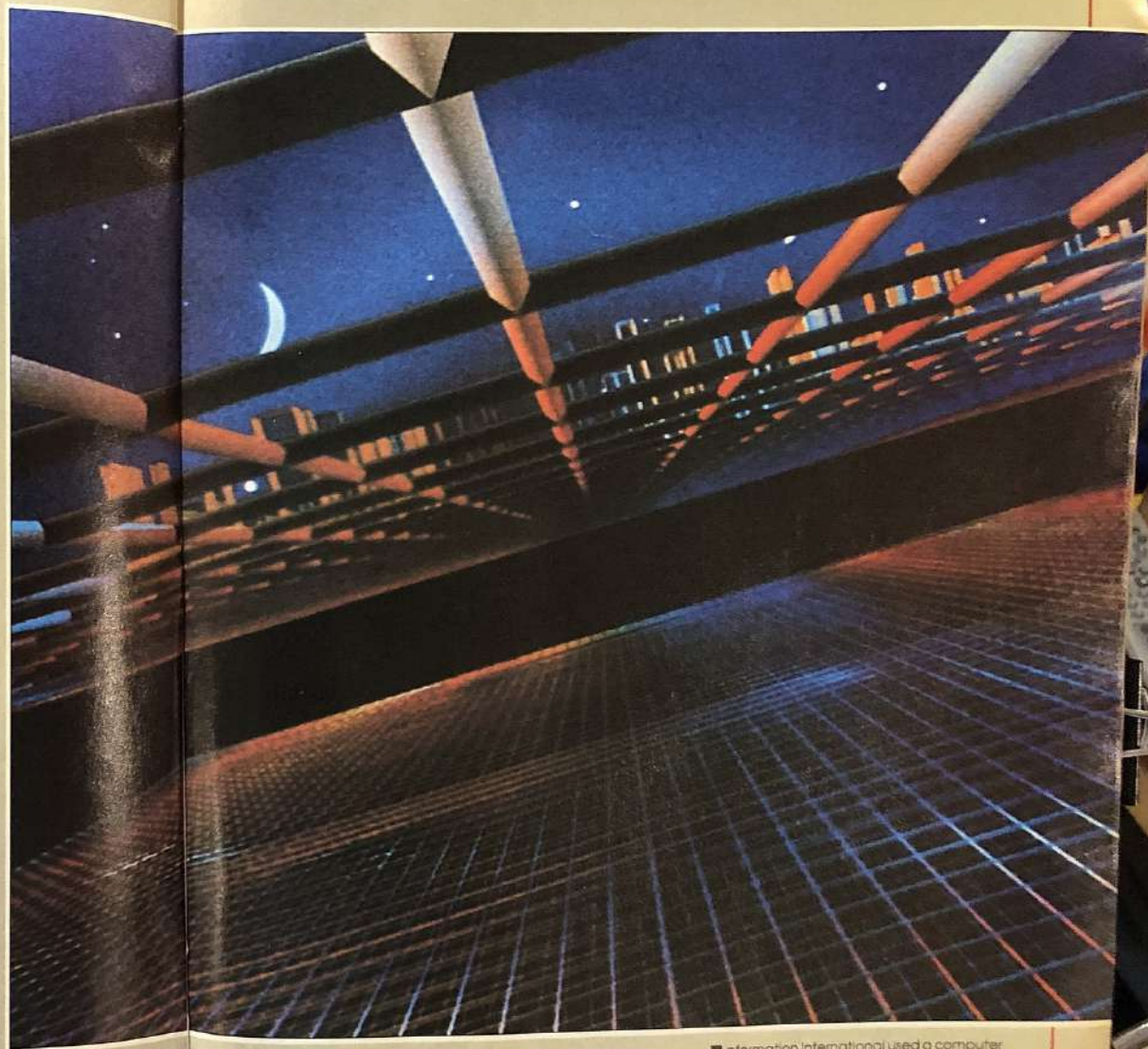
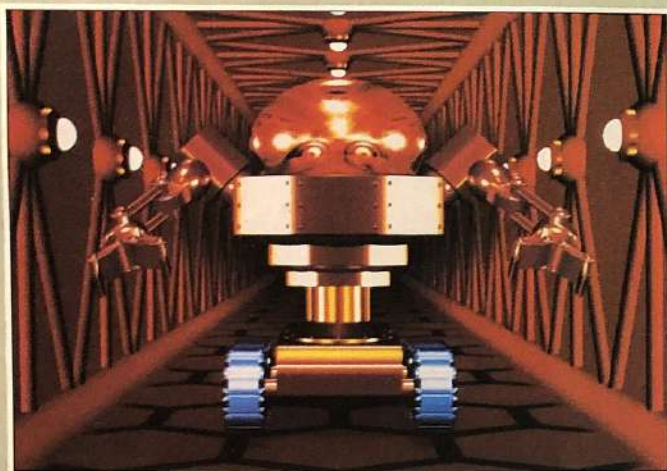
The artistic vista at the top was designed by a real artist. David M., as he is known professionally, collaborated with scientist Jim Blinn to produce multifaceted globes in a setting that echoes the Taj Mahal.

When Frank Crow, of Ohio State University, designed the above columnar scene, he purposely made it complex. But he calls the 20 minutes the computer needed to generate the picture "an outrageously long time."

Gallery

The bubble-headed robot, digitalized at the New York Institute of Technology, will star in "The Works," the first feature-length cartoon animated by a computer. Lights are reflected differently by the glass, steel, and iron surfaces.

Drawn on paper by a Marvel Comics artist, the limp woman below was scanned into a New York Tech computer, which in turn produced a spindly android that took her in its arms as a pair of wondering eyes looked on.



Information International used a computer technique called digital scene simulation to compose this bizarre cityscape, then gave it a title that seemed starkly appropriate: "The Moon over Manhattan as Seen from a Sewer."

SCANDAL IN THE LABORATORY

DISCOVER

THE NEWSMAGAZINE OF SCIENCE
NOVEMBER 1981

THE BODY'S LIMITS

How Fast?
How High?
How Far?

Teen-Age Suicide:
Warning Signals

The Filmless
Camera

A Saturn Portfolio

Searching for a
Malaria Vaccine

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LAWTON H BEURY
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SOUTH HILLS
CHARLESTON 25314

GALLERY

THE LAST PICTURE SHOW



Fine strands in F ring



Rings shadow Saturn's swirling clouds



Tiny ringlets thread a gap in the rings

As they viewed these stunning Voyager 2 photographs of Saturn, its rings, and its moons, scientists at the Jet Propulsion Laboratory had mixed emotions. The excitement of discovery and the joy of success were tinged with an awareness that these spectacular images were, in a way, the last picture show from space.

Next year, for the first time in the memory of some of the younger researchers, no spacecraft will perform its robot maneuvers through an alien sky. No scientist will gape at a new picture of a distant world or shake his head in puzzlement at some bizarre ring or crater or cloud. The planetary blackout will continue at least until January 1986, when Voyager 2 arrives at Uranus. Voyager is expected to survive the five-year hiatus and transmit Uranus pictures and data across 2 billion miles of space back to the earth. But the long layoff could be more detrimental to scientists. Says Voyager's project scientist, Ed Stone, "The Voyager program will continue, but the community of planetary scientists may cease to exist."

Voyager 2's fate is more certain because, as it sped away from Saturn, it was loaded with a backup set of instructions. Should its radio receiver fail, the spacecraft will reconnoiter Uranus on its own and automatically radio the results back. Uranus's gravity will swing the wandering craft on a path to a rendezvous with Neptune, in August 1989. But without further orders from Earth,

Voyager will not know what to do when it gets there.

Despite a balky scan platform that prevented the spacecraft's cameras and three other instruments from obtaining much data on the dark side of Saturn, Voyager 2 still managed to accomplish "two hundred per cent" of its objectives at the distant planet, according to Stone.

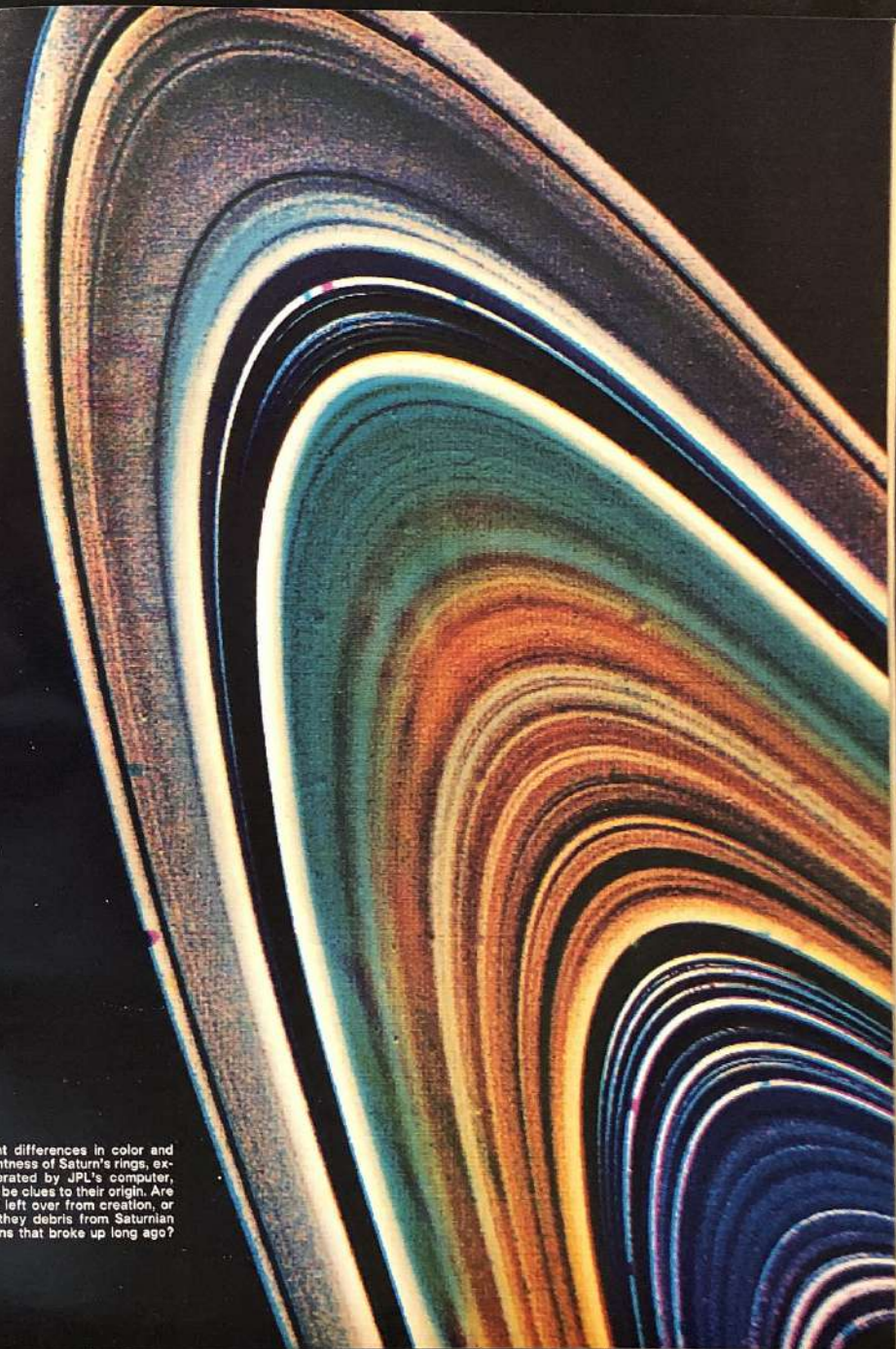
The new close look at Saturn and its icy, enigmatic rings proved that the first fly-by had not exhausted the planet's store of surprises. Voyager 2's scrutiny of the skinny F ring, for example, revealed not the three puzzlingly braided strands discovered by Voyager 1, but up to five parallel strands; meanwhile, a new, kinked ringlet was discovered entwined in the Encke Division, a dark gap that cleaves the bright A ring, the outermost of the major rings.

The pictures also showed an intriguing color difference between the multi-grooved main rings. Some scientists speculated that the colors reflected differences in composition of primordial moons that broke up to form the rings. For two and a half hours during the encounter, Voyager 2 used a light-measuring instrument called a photopolarimeter to monitor light from the star Delta Scorpii shining through the rings and blinking on and off as the star was eclipsed by each ringlet. The result was a cross-section of the entire 40,000-mile-wide ring system, showing details as small as a city block. Where Voyager's cameras saw only a thin

Slight differences in color and brightness of Saturn's rings, exaggerated by JPL's computer, may be clues to their origin. Are they left over from creation, or are they debris from Saturnian moons that broke up long ago?

PHOTOGRAPHS BY JET PROPULSION LABORATORY

DISCOVER / NOVEMBER 1981



GALLERY

band, the photopolarimeter discerned numerous even finer strands. All told, says Voyager scientist Arthur Lane, "there could be a hundred thousand ringlets."

A whole variety of effects, scientists now think, have conspired to shape the rings, some of which appear to be not rings at all but tightly wrapped spiral waves raised by the gravity of more distant Saturnian moons. JPL's Richard Terrile has deduced from pictures taken at different times that the outside part of the B ring is not round but oval, pulled out of shape by the moon Mimas.

Scientists had speculated that Saturn's moons—except for smoggy Titan, one of the largest moons in the solar system—were merely pitted ice balls. But some of the moons show a surprising amount of evolution. Tethys, for example, is nearly encircled by a long trench, as if the moon had long ago expanded and cracked. Enceladus, heated internally by the competing pulls of Saturn and the moon Dione, is crisscrossed by fresh ice flows that have erased the craters from parts of its surface.

Still a puzzle is Iapetus, which plows through space with a leading face as black as pitch and a trailing side as white as snow. One clue is the moon's very low density, which suggests that it is made of frozen methane as well as ice and rock. If it is, the gas may have reacted chemically to form carbon—which would account for the dark stain, according to Stanford astronomer Von Eshleman. Says he, "Part of Iapetus might be dark as pitch because it is pitch." Another theory is that the dark matter was splattered by comets off the outermost moon, Phoebe, and into Iapetus's face. A later close-up of Phoebe showed it to be darker (as dark as Iapetus, in fact) than scientists had thought it was. Says geologist Hal Ma-

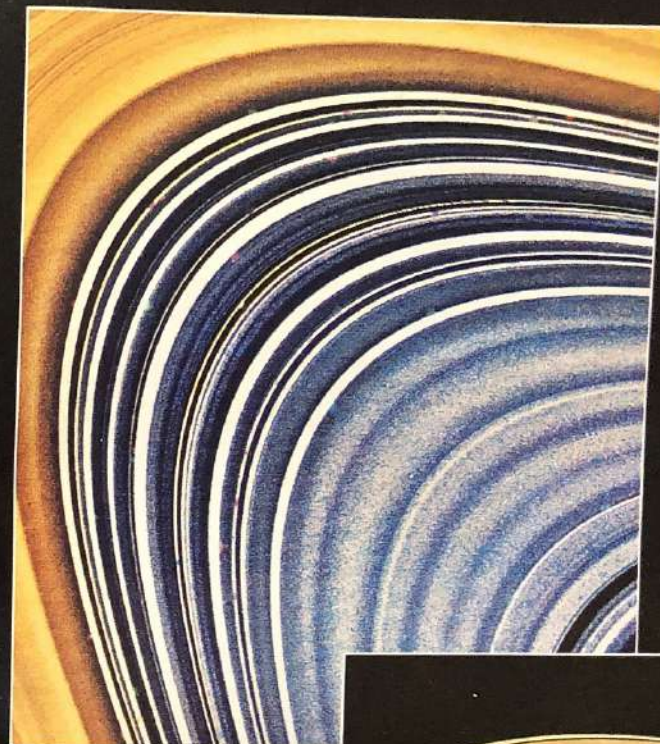
sursky, "All the proposed theses [about Iapetus] are still alive."

Voyager 2's cameras revealed a Saturn pocked with storms and swathed in colored cloud bands. Its muted colors, softer than Jupiter's, are not due to haze, as was previously thought, but to the greater dispersion of the colored molecules in its cloud decks than at Jupiter. Jet streams whip around Saturn at speeds of up to 1,100 miles an hour in alternating easterly and westerly bands. The streams are driven by giant whirling storms spinning like gears along the jet stream boundaries. The

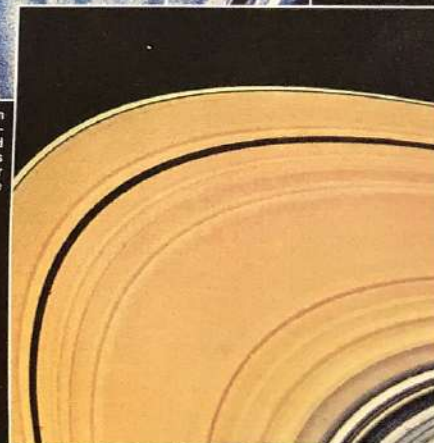
This enhanced view, taken as Voyager 2 approached Saturn, clearly shows the planet's bands of clouds and dark radial streaks in the rings

storms, in turn, are driven by heat rising from Saturn's dense interior. Scientists speculate that helium, slightly heavier than the hydrogen that makes up most of Saturn, is raining toward the planet's center, releasing gravitational energy and thus heating the interior. Some 4.6 billion years after it began forming, Saturn, an ancient world, is still sorting itself out.

—Dennis Overbye



The sharp color difference between Saturn's B and C rings is emphasized in this computer-processed photograph. The B (outer) ring is gold, while the C ring (except for a few B-like ringlets) looks blue



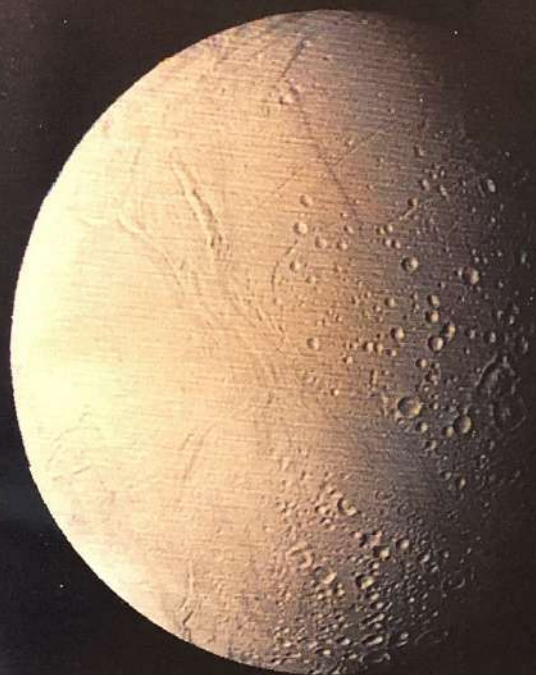
Golden ringlets of the A ring stand out in this enhanced shot. The Cassini Division, at the lower right, has the bluish cast of the C ring

GALLERY

False-color picture, taken at a distance of 9 million miles from Saturn, shows Easter-egg stripes banding the planet's northern hemisphere



Dark, presumably organic, material from an unknown source shows in this view of Iapetus, which is 900 miles in diameter and the outermost of Saturn's large moons



Icy Enceladus is the brightest and smoothest of Saturn's moons, probably because recent melting has erased many of its ancient craters. Scientists think the moon's winding grooves are faults in its crust



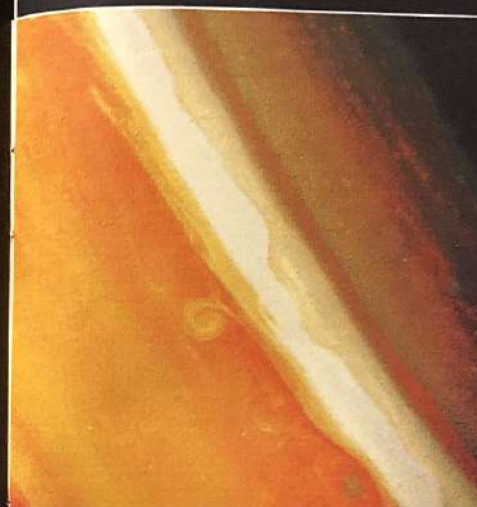
Titan is shrouded by reddish clouds thick with organic molecules. Raining down on the surface, these smog particles may mix with methane snow to make an exotic slush

GALLERY

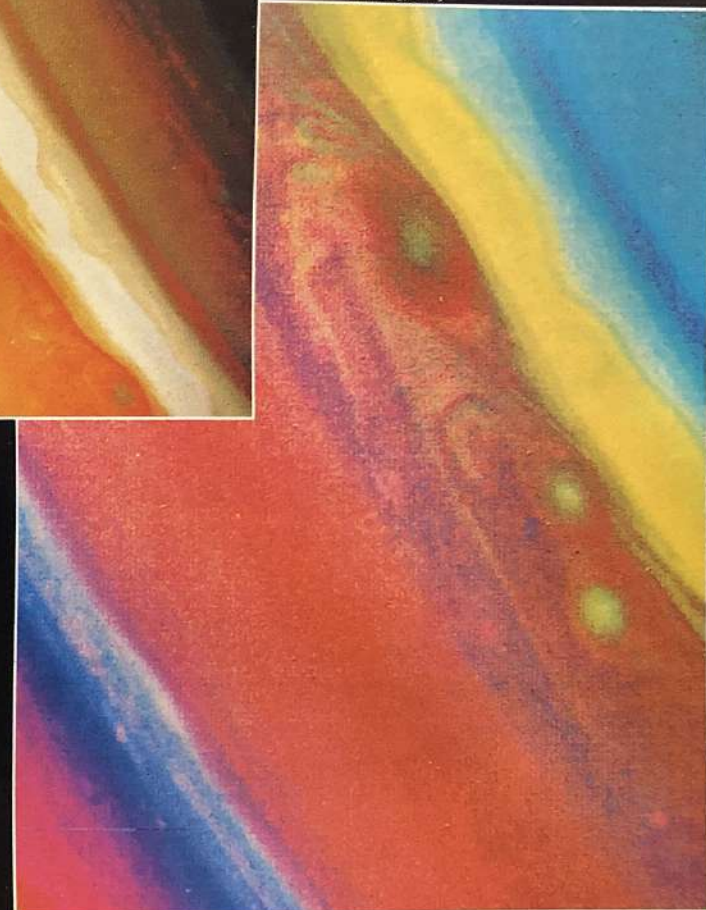
At right: False color reveals storms (ovals) and a wavy jet stream in the northern hemisphere. The jet stream is moving eastward (down) at 300 miles per hour, while the storms are moving toward the west



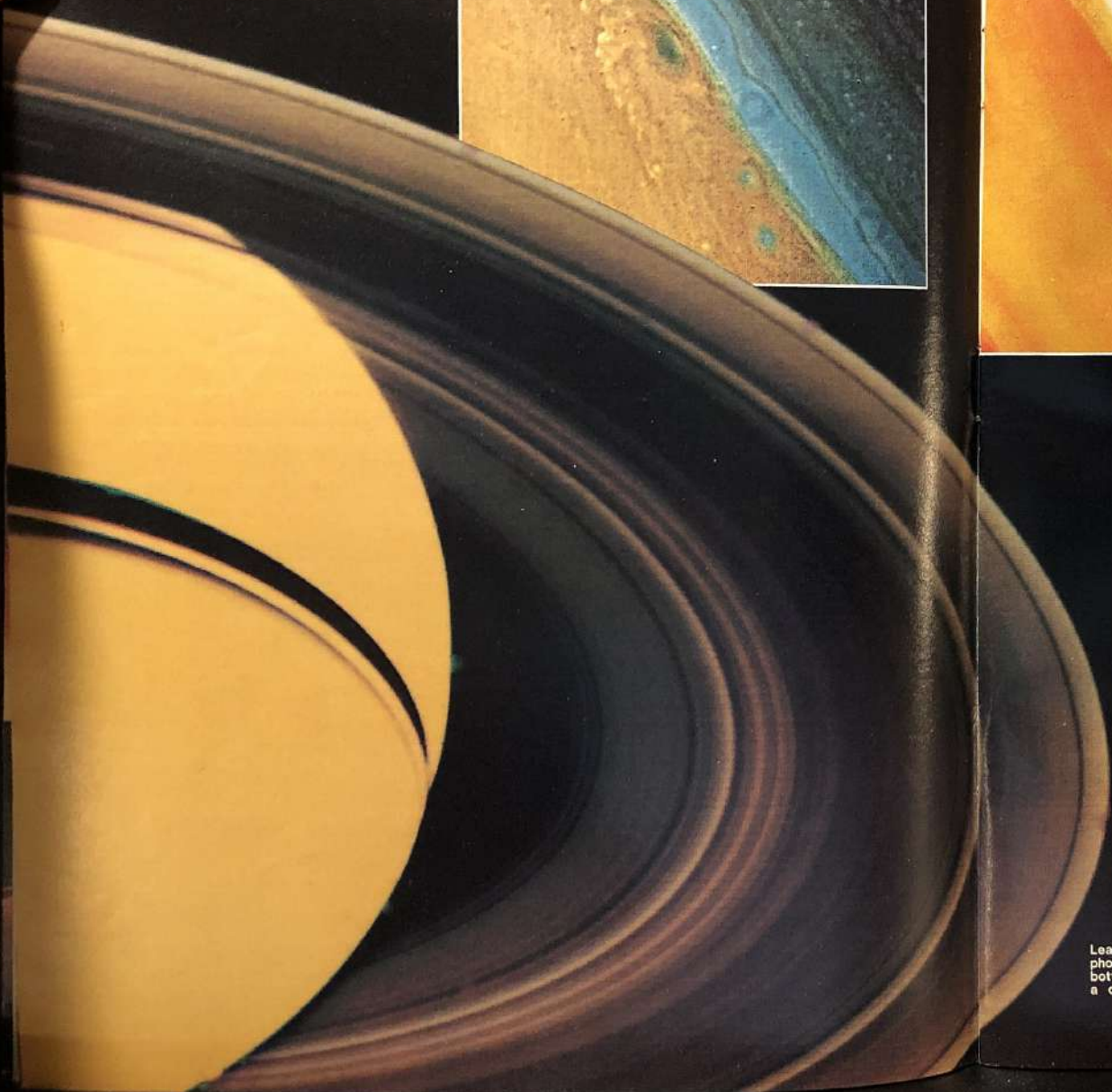
At left: As Voyager 2 watched, a cloud loop formed in this storm hundreds of miles across at the edge of the wavy jet stream, then broke off and drifted, spinning, away



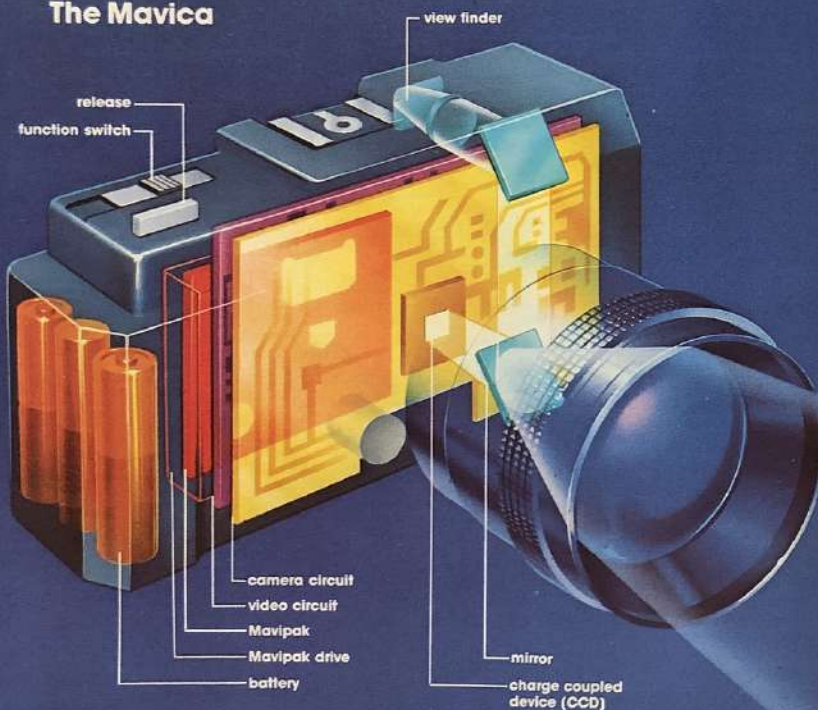
Bright green storms, 2,000 miles in diameter and rotating clockwise, feed a jet stream in this false-color photograph of Saturn's weather



Leaving Saturn, Voyager 2 shot this photograph looking back up at the bottom of the translucent rings from a distance of 2.1 million miles



The Mavica



A see-through view of the workings of Sony's new camera

TECHNOLOGY

PICTURES WITHOUT FILM

Sony's filmless camera ushers in a new era of electronic still photography

by BRUCE SCHECHTER

Spectacular technical advances have created photographic film so sensitive it can "see" in near darkness, film that faithfully reproduces brilliant color and razor-sharp detail, even film—like Polaroid's—with built-in processing laboratories that produce instant photographs. But since the perfection of photographic printing by the French inventor and painter Louis Daguerre, 140 years ago, there has been little change in the basic technology of still photography, which requires chemical reactions to record images on film.

Film may well be around for another 140 years (see page 82 for news of a new kind of film). But photographers will soon have a different way of recording still pictures. In September, Akio Morita, chairman of Japan's innovative Sony Corporation, announced the development of a filmless still camera. Although the new Mavica (for magnetic video camera) is still being perfected, Sony expects to begin selling it in the United States in 18 months or so to anyone with an aversion to conventional film, an urge to try something new, and about \$900 to spare.

The Mavica looks more or less like a bulky, conventional, single-lens reflex camera. Like other cameras, it can be fitted with wide-angle, normal, and telephoto lenses; it has shutter speeds of

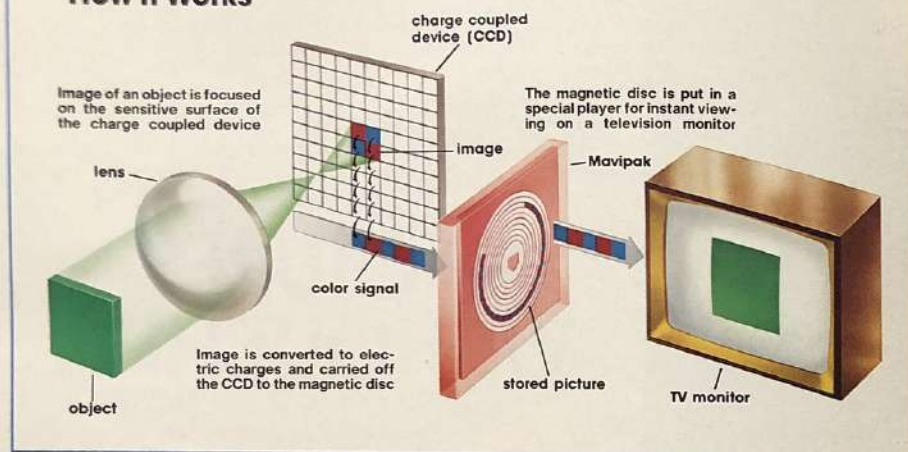
from $1/60$ to $1/2000$ of a second; and it has automatic exposure control. But there the similarity ends.

Instead of using film, the camera records images with an electronic marvel called a charge coupled device (CCD), which is capable of converting patterns of light focused on it by the lens into a stream of electrical impulses. These are registered on a whirling magnetic disc only about two inches in diameter that can store as many as 50 color photographs. Unlike film, the disc requires no processing, and the images can be stored on it indefinitely without fading. The disc can be popped out of the camera and immediately inserted into a special player that reproduces the images in glowing color on a standard television set. Sony estimates that the discs will cost less than \$3, and says that they can be either stored or reused to take new pictures, just as magnetic sound tape can be erased and reused.

The Mavica is not so much an inventive breakthrough as a daring combination of technological advances made during the past decade or so. Its works include integrated circuits, a microprocessor, an advanced magnetic storage device of the type used in computer systems, and the all-important charge coupled device.

One of the major advantages of the CCD over the conventional vidicon

How It Works



tubes in television cameras is that the CCD is simply a flat plate that can fit easily into a small camera body. The vidicon tube, by contrast, looks like a miniature picture tube from a television set, and takes up much more space. The CCD also uses less power than a vidicon tube, so its electronics are less bulky.

Charge coupled devices are coming into use in computer memories, telephones, and many other appliances. CCDs with light-sensitive surfaces are already being used in advanced television cameras and in conjunction with astronomical telescopes. The versatile devices were invented by Willard Boyle and George Smith at Bell Labs in 1969 as an outgrowth of Bell's research into bubble memory devices.

The surface of a light-sensitive CCD consists of a metal oxide and silicon, and it is divided into a grid of microscopic squares. In the Mavica, the camera lens forms an image on the grid, each square receiving an amount of light dependent on the pattern of light and dark areas in the image. An electric charge is generated in each square that is proportional to the amount of light striking that square. To "read" these tiny charges, the circuitry of the device applies an electric field that pushes them across the entire light-sensitive grid. The charges are shifted from one square to the next, like a message moving across a

Times Square advertising sign, until they reach the edge of the grid. As each charge leaves the grid, it is measured, and information about its size and exact position on the grid is recorded magnetically in such a way that the charges can be reassembled to re-create the original image.

Sony was not the first to benefit from the remarkable capabilities of the charge coupled device, which is so sensitive that it can record a single photon, or particle of light. One of its most dramatic successes was scored in 1977 at the University of Arizona's Mount Lemmon Observatory, when astronomer Bradford Smith, on a whim (there was already a CCD camera being used in his lab), substituted a CCD for a conventional photographic plate while training a 61-inch telescope on the planet Uranus. The CCD-equipped telescope was able to record detail so faint that Smith found the planet to be about 2,500 miles larger in diameter than had been previously supposed.

The ability to see even in faint light is a feature of the Mavica, as well; it has a sensitivity equivalent to a film speed of 200 ASA, comparable to some of the most sensitive commercial color films.

But Sony has a long way to go before its filmless camera can compete in picture quality with conventional cameras.

The Mavica's major drawback is that its light-sensitive grid is much coarser than the particles of light-sensitive chemicals in the emulsion of conventional films, and the images it produces are therefore much fuzzier. In fact, the Mavica's image is divided into only 350 lines per inch, less resolution than that afforded by a home television set (525 lines per inch).

Morita predicts that by the time the Mavica is marketed, its resolution will match that of a television set. That is still far below 35-millimeter film quality, which is the equivalent of about 1,500 lines per inch.

Clearly, Sony faces major challenges with its Mavica. Even if image quality is improved and the price is reduced somewhat, the Japanese electronics giant may have difficulty finding a mass market. "Why would anyone want a camera that takes pictures only as sharp as those on your TV?" asks William Webster, vice president of RCA Laboratories. "It's an idea we've discussed for years, and we've decided there's no market for it."

Nevertheless, U.S. manufacturers are known to be exploring the possibilities of filmless cameras, perhaps delaying their own plans until Sony's camera is tested in the marketplace. But if Morita's gamble pays off, Sony may be the first to reap the benefits of a revolution in home photography.

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GREEN LIGHT FOR THE NEUTRON BOMB

Reagan's decision places the world's most controversial weapon under new scrutiny

by BRUCE SCHECHTER

When Jimmy Carter decided to put the neutron bomb on the military back burner in 1978, the debate over the bomb—which centered on its peculiar ability to kill people while largely sparing their property—was temporarily halted. But Carter hedged his bet. Although he decided not to initiate production of the bomb, he kept the rest of the program alive: neutron bomb parts would be built but not assembled into weapons. For three years military warehouses filled with bomb components, collecting dust and keeping America's option open.

In August, President Ronald Reagan decided to exercise that option. He ordered the assembly of battle-ready neutron bombs, calling them "a deterrent to conflict." Reagan's decision rekindled world-wide controversy over these lethal new weapons, and inspired arguments from both advocates and opponents of the bomb that generally threw more heat than light on the true nature of the weapon.

What, exactly, is a neutron bomb? How does it differ from other weapons, and how would it be used?

According to Pentagon purists, the bomb is misnamed. A neutron bomb is not a bomb at all, they say. Bombs are dropped from airplanes, but the neutron weapon is designed for delivery by a Lance missile or an artillery shell. The official preferred name, therefore, is "enhanced-radiation warhead." That formal designation takes into account the fact that not only is the so-called neutron bomb a ballistic weapon, but also that it is not radically different from other nuclear weapons. It is, actually, a close cousin of the familiar fission (atomic)

and fusion (hydrogen) bombs. Because of that kinship, one way to understand the neutron bomb is to look at the family of weapons from which it springs.

All nuclear explosions draw their energy from the bonds that "glue" elementary particles together inside atomic nuclei. The bombs that destroyed Hiroshima and Nagasaki 36 years ago were outgrowths of a 1938 discovery by

German physicists Otto Hahn and Fritz Strassmann, who, working under the Nazi regime, found that when the nucleus of a uranium atom is struck by a neutron it sometimes breaks apart into fragments and yields some leftover neutrons that emerge as radiation. American scientists subsequently learned to use these neutrons to initiate chain reactions, and so the mushroom cloud was born.

A few years later, American laboratories discovered how to bring about nuclear fusion, the energy source of both the stars and hydrogen bombs. In fusion reactions, nuclei of light atoms like those of hydrogen are forced together to form heavier nuclei, releasing vastly more energy than the fission reaction that powered the first atomic bombs. Hydrogen fusion bombs differ from their fission-bomb antecedents in another significant way: they produce immense numbers of neutrons not needed to sustain fusion reactions, and these neutrons stream out of a blast in the form of lethal radiation. In fact, a hydrogen bomb is a neutron bomb.

But in the days when hydrogen bombs were being developed, they were seen as strategic weapons intended to demolish large cities. For this, maximum blast power was demanded, and the escape of part of a bomb's energy in the form of neutron radiation seemed undesirable. To rechannel this energy into the blast, scientists designed an ingenious jacket for the basic hydrogen bomb.

The jacket is made of uranium—not the kind used to fuel fission bombs, but a more common variant (isotope) known as uranium-238. Ordinarily, uranium-238 cannot sustain a chain reac-

tion leading to an explosion, but when it is blasted with the high-energy neutrons streaming from a hydrogen bomb explosion, it captures these neutrons and explodes, adding its own energy and that of the neutrons to the overall power of the bomb. It required only removal of this jacket and some design changes to produce the neutron bomb, and to stir the present controversy.

The effects of the neutron bomb differ from those of "conventional" nuclear weapons in several important ways. For one thing, a neutron bomb is designed to contain much less nuclear explosive than most hydrogen bombs. Because the absence of a uranium jacket further reduces its energy, its blast power is comparatively small, equivalent to some 1,000 tons of TNT; a typical hydrogen bomb yields several thousand times this amount. This means that the blast and heat effects of the neutron bomb are far smaller than those of its big brothers. In the words of Samuel T. Cohen, the Defense Department consultant credited with developing the neutron-bomb concept, it is just "sort of a mini-hydrogen bomb, a micro-mini-hydrogen bomb." It is so diminutive—in nuclear weapons terms—it can be squeezed into an 8-inch howitzer shell.

But while nearly all the energy of a hydrogen bomb is consumed in producing blast and heat, neutron bombs of the type built as warheads for the Lance missile behave differently. They convert only 65 per cent of their energy into heat and blast, 5 per cent into lingering radioactive fallout, and the remaining 30 per cent into radiation. This radiation consists chiefly of streams of neutrons moving at speeds approaching that of light, and is one of the most dangerous forms of radiation for human beings (or any other form of life).

Nevertheless, the neutron bomb is still a hydrogen bomb, and despite its special characteristics, it would cause destruction far greater than any conventional weapon.

How would it be used in war? Army strategists describe it as a "theater nuclear weapon," and regard its main potential theater as Western Europe. Massive buildup of Soviet forces in Eastern Europe over the years has, according to Secretary of Defense Caspar Weinberger, "turned the European theater balance against the West, requiring the modernization of NATO's deterrent forces, as well as of our own capability to deter Soviet threats in other theaters." The Reagan administration regards the neutron bomb as a possible redress of that balance.

The Lance missile: vehicle for the neutron bomb



1-kiloton neutron warhead

1,400 ft. Severe destruction
2,500 ft. Tank crews killed
3,000 ft. Death in about 6 days
4,000 ft. Radiation sickness resulting in death in weeks



10-kiloton fission warhead

3,000 ft. Severe destruction, tank crews killed
4,000 ft. Radiation sickness resulting in death in days or weeks
5,000 ft. Blast damage but little radiation



ILLUSTRATIONS BY MARK KAPLAN

If a war were to break out in Western Europe, strategists believe, it would be fought in West Germany, starting as a war of tanks and artillery, in which the odds would heavily favor the Communist side; the Soviets and their Warsaw Pact allies have some 19,500 tanks; about 7,000 are available to NATO forces. According to Weinberger, the neutron bomb is "designed to stop a massive invasion by enemy armor that might otherwise roll, in blitzkrieg fashion, across democratic Europe and the territory of our principal allies." NATO has conventional nuclear weapons to counter this threat, but the destructive power of such weapons would wreak havoc on the homeland of those who, in Weinberger's words, were "unlucky enough to live near where the war was taking place." The neutron bomb, it is claimed, would cause less physical damage to buildings, farms, and factories.

Such is the administration's thinking on the neutron bomb. But to assess that concept dispassionately requires a look at the actual damage a neutron warhead would probably cause.

On the battlefield a neutron bomb would be detonated some 500 feet in the air above enemy troops. This height,

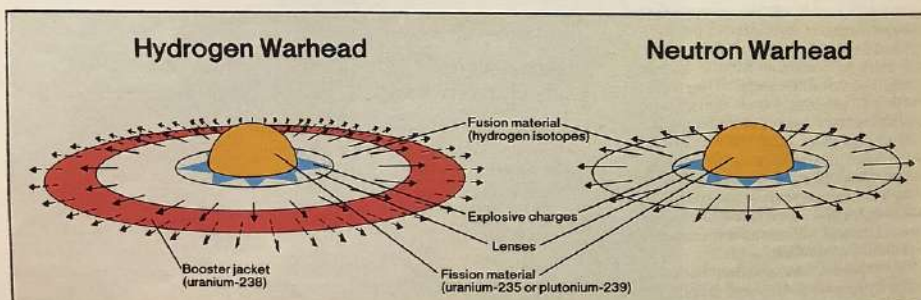
amounts of radiation. The information gained from this work has been extrapolated to make informed guesses about the effects of real neutron bombs on real people, and these guesses may be faulty.

Nevertheless, it is assumed that up to 2,500 feet away, the radiation would be enough to kill infantrymen and so incapacitate soldiers in their tanks as to render them "immediately and permanently disabled," as the U.S. army puts it. While tests have shown that the crew of a tank protected by several inches of armor would receive only half as much neutron radiation as unprotected troops, doses would still be high enough to stop massive tank assaults dead in their tracks. Beyond that radius, the dose, while smaller, would still cause "immediate transitory incapacitation." Within five minutes after a blast, troops as far as 3,000 feet away would become too sick to fight, perhaps recovering enough to function a half hour later. They would, nevertheless, face certain death from radiation sickness five or six days later, and as "walking dead," create a problem for which there is no real precedent in the history of warfare.

One school of military speculation holds that they would fight like kami-

radiation victims would eventually die. Beyond about one mile and a quarter, radiation would probably cause few deaths, but those exposed could face weeks of nausea, vomiting, loss of appetite, bloody diarrhea, loss of hair, and skin disorders. The probability of their developing cancer later in life would be greatly increased, and their offspring, if any, would be marred by an increased incidence of birth defects.

That is how the Pentagon expects the neutron weapon to perform, and planners believe that such performance meets military needs. However, critics feel that tactics based on neutron bombs depend too much upon the enemy's behaving according to theory. Says Cohen: "What we've done is set up a preferred scenario that makes our policy look attractive but assumes that the Soviets are going to let us do all that. But they'd be damned fools if they did." Cohen, for one, believes that the Soviets, conscious of NATO's vulnerability, would use nuclear weapons to clear the battlefield at the outset of any invasion, "for no other reason than common sense and logic." In the words of George Kistiakowsky, former presidential science adviser: "If you use a neutron



Schematic diagram shows the small but significant difference between hydrogen and neutron warheads

because it coincides with the diameter of the fireball produced by the explosion, prevents the fireball from touching the ground, and eliminates much of the subsequent fallout that would otherwise result. Still, everything within about 1,400 feet of "ground zero" would be destroyed.

It is difficult to predict accurately the effects on human beings. Military estimates are based on analyses of the effects of atomic bombs on the people of Hiroshima and Nagasaki, as well as on laboratory experiments in which animals have been exposed to varying

kaze pilots, risking all in mass suicide attacks. They would presumably be fired by the utmost hatred for the enemy who had doomed them: the walking dead would be potent adversaries.

On the other hand, troops in the vicinity of a neutron bomb blast might realize that many among them were doomed without necessarily knowing which ones. A general feeling of defeat and despair could shatter fighting morale, inducing some soldiers to flee and others to resign themselves to acceptance of their fate.

Even about 4,000 feet away, many ra-

bomb on the Soviets, they are sure to dish out everything they've got, namely their full-scale nuclear weapons."

Other critics include doctors who view the effects of any nuclear bombing as comparable to a man-made epidemic so staggeringly lethal that it would preclude any help from the medical profession (see Essay by Lewis Thomas on page 32).

But deterrent or folly, the neutron bomb is a reality. Whether, as some believe, it has brought the world closer to nuclear warfare by making the unthinkable thinkable, remains to be seen. □

ILLUSTRATION BY NICK FASCIANO

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ASTROGEOLOGY

A blast on the Red Planet may have launched some rocks on a 180 million-year trip to Earth

METEORITES FROM MARS?

by MARCIA BARTUSIAK

Some 180 million years ago, an immense meteor or a comet streaked through the thin air of Mars and plunged with the force of many hydrogen bombs into the surface of the Red Planet. Driven by the stupendous energy released by that blast, billion-year-old chunks of volcanic rock several yards in diameter were hurled into space. There, they wandered for millions of years, at times colliding with other solar system debris. Eventually, by chance, some crashed into Earth,

where they are now baffling scientists and prompting disputes.

This scenario broadly outlines a theory that some scientists are coming to regard as a likely explanation for some of the strangest of all meteorites—the shergottites, nakhlites, and chassignites. What makes these meteorites so unusual is their apparent age; they seem to be much younger than any meteorite should be. Most meteorites are thought to be chunks of rock and scraps of iron and nickel left over from the

birth of the solar system more than 4.5 billion years ago.

While thousands of these older meteorites have been collected throughout the world, the young meteorites have been discovered in only nine places. One fell in 1865 near Shergotty in northeastern India, and was named for the town. Nearly a century later, a similar meteorite was found near Zagami, Nigeria; others have turned up in France, Australia, Brazil, Antarctica, and the state of Indiana. What they seem to share is a

ILLUSTRATION BY GEORGE V. KELVIN



Young meteorites: where and when they fell to Earth

genesis from molten lava a mere 1.3 billion years ago—remarkably recently, in astronomical terms. This corresponds to a time when lava was still solidifying into rock on the Martian surface. Some of the meteorites also carry evidence of a cataclysmic event 180 million years ago. By the time these peculiar rocks were formed, the commoner kind—thought to have come from the asteroid belt between Jupiter and Mars—had been wandering for a few billion years. What could account for the newcomers?

George Wetherill, of the Carnegie Institution of Washington, one of the scientists who has studied the Martian meteorite theory, recalls that a few years ago a French colleague was struck by the similarity of these young meteorites to the ordinary basalt rocks that were born in the lavas of Earth. "Maybe these meteorites are pieces of Earth, after all," the Frenchman said.

Wetherill knew this was impossible. For one thing, some of the specimens had actually been seen near the end of their long voyages, blazing through the sky as shooting stars before striking the earth. Unable to explain the Earth-like nature of rocks from the sky, Wetherill quipped, "They might as well have come from Mars"—an idea that had already occurred to others.

Spurred on, Wetherill and several like-minded scientists began a serious examination of the notion that the odd meteorites had come from a large planet on which volcanoes were still active. Knowing that Mars was spewing mol-

ten rock from its volcanoes about a billion years ago, the scientists started honing their ideas. A review of the evidence, to be published this winter in *Proceedings of the 12th Lunar and Planetary Science Conference*, observes that "Mars is the only plausible parent body" for these young rocks.

The authors of the review, planetary geologist Charles Wood of NASA's Johnson Space Center and geochemist Lewis Ashwal of the Lunar and Planetary Institute, both in Houston, write that the stones "differ chemically, petrologically, physically, and magnetically from other meteorite types," and in such a way as to suggest Mars as the source. Wetherill had earlier published a possible explanation of how a rock could have reached Earth from Mars. If a large meteorite or comet hit Mars hard enough, he said, it might have vaporized large amounts of underground ice, forming steam jets. Combined with the energy released by the impact of the meteorite, the propulsive force of the expanding gas might have been great enough to launch the Martian rocks on interplanetary journeys.

Some scientists argue that the physics of ballistics seems to weigh against such a theory. In the absence of detailed calculations demonstrating that a rock could be shot from Mars to Earth by such a mechanism, they say, the case for the Mars theory remains dubious.

Yet one of the classes of young meteorites under study, the shergottites, did, in fact, undergo a substantial shock at one time. One of the crystalline minerals from which shergottites were

formed, plagioclase, was transformed by some impact into a glassy substance called maskelynite. The transformation, scientists calculate, would have required a sudden burst of pressure equal to 4.5 million pounds per square inch.

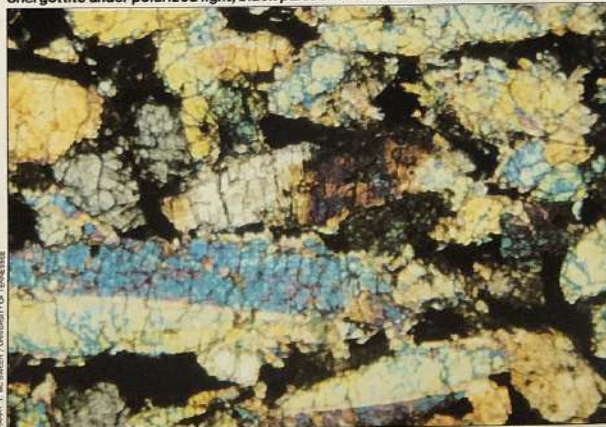
By measuring the decay of the radioactive substances in the meteorites, Laurence Nyquist, Donald Bogard, and others at the Johnson Space Center estimated the time of that shock to be about 180 million years ago. Says Nyquist, "That could be the signature of the impact on Mars," the time when the volcano-born rock was finally blasted away. Another hint of Martian origin comes from the composition of the young meteorites. Edward Stolper, now with the California Institute of Technology, reported in his 1979 doctoral thesis that the chemical composition of shergottites bears a striking similarity to that of Martian soil scooped up by the Viking lander.

The case for Mars is further strengthened by the difficulty in arguing for other planets and moons of the solar system as possible points of origin. The bodies considered—and discounted—as cradles of the young meteorites:

- Venus. Its dense atmosphere and strong gravitational field would make escape of any material very difficult.

- The Moon. Its gravity is weak and relatively easy to escape, but the moon was not producing new volcanic rock a billion years ago. Even if it had been, such rocks would have reached Earth quickly because it is so close and has a strong gravitational pull. But judging by the

Shergottite under polarized light; black parts show effect of shock



wear and tear on the meteorite surfaces caused by cosmic ray bombardment, scientists are fairly sure that the chunks of rock drifted in space for millions of years.

- Earth. Harry McSweeney, of the University of Tennessee, points out that it is unlikely that a rock, if it could be kicked off the earth, would remain in orbit for millions of years before plunging back to the surface. Also, in the meteorites, the ratio of iron to manganese and of two rare forms of oxygen to the plentiful variety is quite different from the proportions of those on Earth. Another objection is that virtually no magnetic field was present when the meteorites were formed. This implies, Wood and Ashwal reason, that the puzzling meteorites could not have cooled from liquid rock on or near the earth, which has a relatively strong magnetic field.

- Io. A Voyager space probe found that this moon of Jupiter was volcanically active, but its mineral composition does not match that of the meteorites. In any case, no one can imagine how any fragments from Io could escape the immense pull of Jupiter.

Still, the fact that other bodies in the solar system seem not to qualify as sources of the young meteorites does not settle the argument in favor of Mars. Says Bogard, "It's sheer speculation at this point, but it's healthy speculation." Adds Nyquist, "If they aren't from Mars, the real origin is likely to be just as bizarre."

A major stumbling block to the Mars hypothesis is dynamics. Says Friedrich Hörz, a NASA expert on cratering, "It's not impossible for a chunk of Mars to fly out into space after an impact, but it's pretty hard to make it happen." Hörz calculates that the shock experienced by the shergottites would have accelerated them to a speed of about six-tenths of a mile per second, only a fifth the velocity needed to escape from Mars. Says he: "It's difficult to quickly eject something at full escape velocity without vaporizing it. An added boost from volatile material converted to gas might change the picture, but we just don't know yet."

In fact, some of the meteorites in question do not even appear to have been subjected to shock. Among them are a hail of meteorites that fell at Nakhla, Egypt (hence the name nakhlites), in 1911 and killed a dog (tempting Wood to entitle his talks on the subject "Martian Missile Maims Mut"). But how could anything be blasted from Mars and come through unscathed? One possible answer, Wood says, is that



Ashwal and Wood examining a young meteorite at Johnson Space Center

each of the young meteorite types came from different depths, and thus the shergottites were exposed to greater shocks than were the nakhlites and chassignites.

Another, indirect objection to the Martian theory is that no meteorites from the moon have ever turned up on Earth, despite the fact that the moon, too, has been exposed to a bombardment by very large meteorites, and is much closer than Mars.

Such difficulties have led to alternative theories to account for the young meteorites, including the possibility

that they were somehow formed late in the solar system's history in the interior of a large asteroid. But these theories also have troublesome weaknesses, and, as Wetherill, who is still undecided, says, "A violent collision in the asteroid belt might prove to be the best explanation."

But Wood stands firm with the Martian theory. "In a sense," he says, "we've settled on the least preposterous idea. To quote Sherlock Holmes, 'When you have excluded the impossible, whatever remains, however improbable, must be the truth.'"

January 1981

DISCOVER

THE NEWSMAGAZINE OF SCIENCE

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THE GREAT
SATURN FLY-BY

THE PLANETS

LORD OF THE RINGS

Voyager's tour of Saturn yields
an astonishing volume of knowledge
as well as spectacular pictures
by DENNIS OVERBYE

The day after its close encounter Voyager 1
looked back across 930,000 miles of space
and took this picture of Saturn's rings and their
shadow on the planet's overexposed crescent

THE PLANETS

It was seven o'clock on a foggy Tuesday morning in Pasadena, California. At Caltech's Jet Propulsion Laboratory, tucked against the foothills of the San Gabriel Mountains, a knot of hollow-eyed scientists and journalists, drinking coffee from Styrofoam cups, were staring at a television screen. The images they saw had been transmitted over 947 million miles of space from the Voyager 1 spacecraft, now only 33 hours from its long-awaited rendezvous with the ringed planet Saturn.

Titan, Saturn's largest moon, a fuzzy, smog-shrouded, featureless ball, filled the screen, and the group leaned forward, searching futilely and a bit impatiently for details on that blank face.

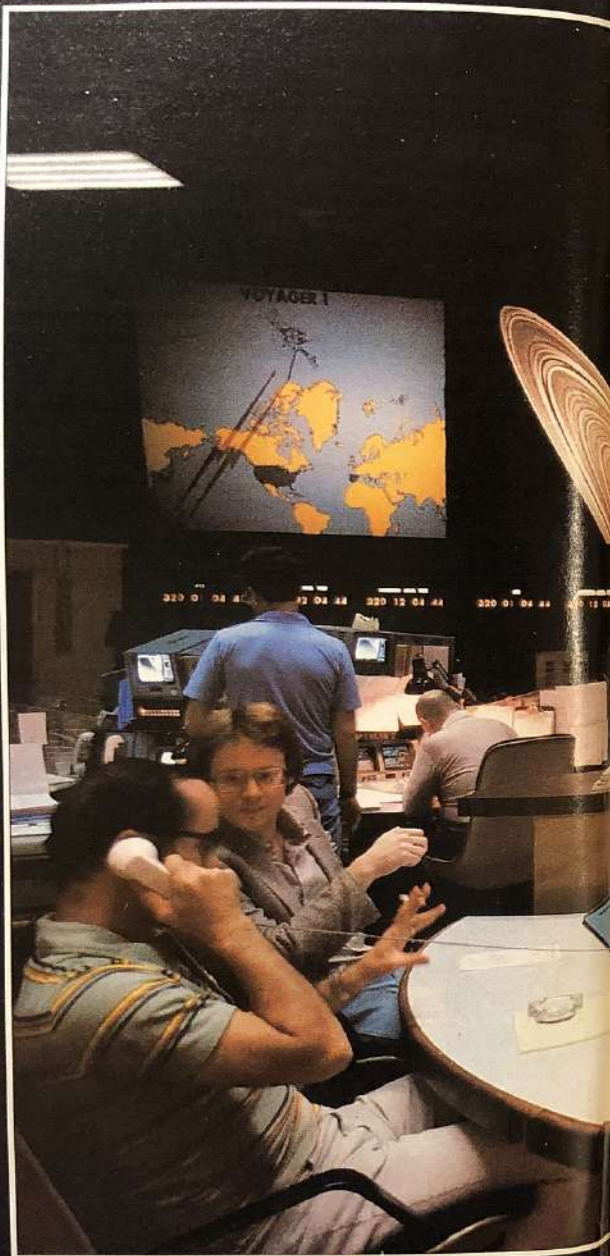
"Well," grumbled one, "it looks like nature finally made a boring satellite." Fifteen hours later, after passing within 2,500 miles of Titan, the spacecraft plunged through Saturn's cluttered ring plane, cruised past the planet's south pole and then soared back up past the rings, swiveling back and forth like a goggle-eyed tourist to view sights it and the rest of the world were seeing for the first time.

There was a time when Voyager scientists feared that the spectacular flybys of Jupiter, with its swirling colors and diverse worlds, would be a hard act to follow. It seemed likely that Saturn would appear rather bland in comparison, its colors muted, its satellites grey snowballs. And, as one Voyager scientist said, "We thought we had the rings pretty well figured out."

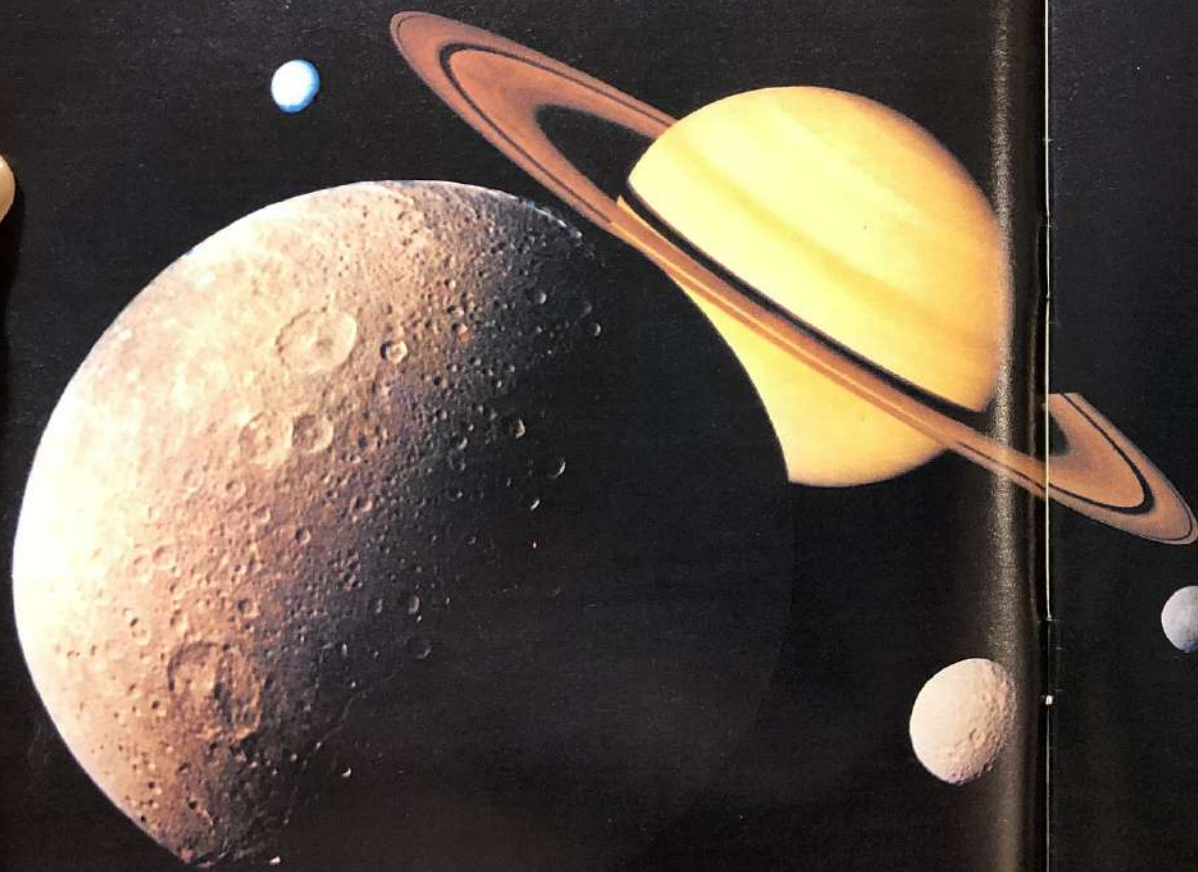
That was before Voyager's all-seeing instruments dissolved the solid-looking rings into what looked like hundreds of golden phonograph-record grooves, replete with dark spokes, braids, perhaps lightning; before Saturn's cracked and pitted moons, bearing the scars of primordial anguish, swam into view, blotched white and black as if splashed by a crazy cosmic paintbrush. Voyager tracked storms beneath Saturn's haze that were thousands of miles across, whipping around the planet at speeds as great as 900 miles an hour. Even smoggy Titan, cleverly unveiled by radio waves and betrayed by its own infra-red and ultraviolet emissions, began to reveal itself as a cosmic deep freeze, possibly washed by nitrogen rains and hydrocarbon fallout, where the evolution of life may have been brought to a frigid standstill in its early stages.

In the Space Flight Operations Facility, JPL's deep-space navigators track Voyager 1 on consoles and TV monitors as it approaches Saturn

SCIENCE/ALPINE/CONTRACT



THE PLANETS



lions of miles from its goal, began detecting regular radio bursts from the planet. By tuning the bursts, presumably from electrons trapped in Saturn's magnetic field, Voyager scientists were for the first time able to calculate accurately how long it takes the planet to rotate once on its axis: 10 hours 39.4 minutes. The radio noise also presented them with a puzzle. Saturn's magnetic field, unlike that of other planets, is aligned with its rotation axis. This configuration should not produce the radio bursts unless something inside the planet is distorting its magnetic field and making it asymmetrical. Most of Saturn's radio noise seems to be coming from one side of its northern hemisphere, but scientists have no clue as to why.

Voyager arrived at Saturn, swooping to little more than 77,000 miles above the cloud tops, an unfashionable 43 seconds ahead of schedule and only 12 miles from its imaginary target in space. Reason for the tiny discrepancies: scientists had been uncertain about the precise orbit of Titan, which tugged a little harder than anticipated on the spacecraft as it approached the ringed giant. Like Jupiter, Saturn turned out to be pocked with giant swirling storms, thousands of miles across; those on Saturn are harder to see from Earth because the clouds form deep in the planet's frigid atmosphere and are obscured by high-level haze. These eddies, as astronomers call them, are caused by heat flowing from the planet's interior; they are thought to drive the ferocious jet streams that make up the light and dark bands on Jupiter and Saturn. On Jupiter, the winds in adjacent bands blow in opposite directions. But Voyager meteorologists found that on Saturn all the jet streams flow in the *same* direction. The maximum wind velocity, near the equator, is 900 miles an hour—four times the speed of Jupiter's winds.

The source of the heat bubbling up through Saturn's clouds was also a mystery that Voyager could not solve. Pioneer 11 had found that Saturn radiates almost three times as much energy as it receives from the sun. Some scientists had suggested that the helium might be settling deeper inside Saturn's atmosphere than the hydrogen, releasing gravitational energy in the form of

Montage of Saturn and some of its moons, assembled by JPL scientists. Clockwise from upper left: Rhea, Titan, Mimas, Tethys, Dione, and Enceladus.

THE PLANETS



Enhanced close-up of the moon Titan shows that its thick atmosphere is overlaid by a thin haze layer. Inset: From a distance of 2.6 million miles, Titan is a fuzzy reddish ball

"helium rain." But this would leave Saturn's outer layers relatively deficient in helium, and Voyager found that this was not the case.

For astronomers, the journey past Saturn's gloaming rings was like a trip back in time, scientists believe that the solar system itself condensed out of a similar disc of rubble and gas 4.5 billion years ago. "We're excited about seeing structure in the rings," said NASA scientist James Pollack, "because it may give us a hint of how matter came together to make the planets." That structure has turned out to be more complex than anyone could have guessed. Said project scientist Ed Stone, "We need to resort to a whole new repertoire of physics to explain the rings."

Before Voyager, six rings were known or suspected to exist around Saturn, designated by letters in order of their discovery. The brightest and best known are the A, B, and C rings (the out-

ermost of which is A), visible through small telescopes. The A and B rings are separated by a dark gap, called the Cassini Division. Some astronomers had reported seeing a dark D ring inside the C ring, but its existence was doubted. Farther out from Saturn and coinciding with the orbit of the moon Enceladus is a broad, faint trail of material known as the E ring, which has been photographed from Earth. Finally, when Pioneer 11 visited the system in 1979, it photographed a narrow, faint ring just outside the A ring, which was called the F ring. Voyager 1 confirmed the existence of all these rings, although the D ring appeared so faint in the spacecraft sensors that Smith now doubts that Earth-based astronomers actually could have seen it ("I can say this because I was one of the people who thought he saw it"). The spindly spacecraft also spotted a seventh ring, somewhere between E and F, by the shadow it cast on a passing moon.

When Voyager 1 was still millions of miles from Saturn, the rings began to resolve into dozens of ringlets and dark grooves, rings within rings. By the time the spacecraft made its closest approach, astronomers had given up trying to count them all; Smith estimated that the number of individual concentric features could go as high as 1,000—including at least 20 faint ringlets within the Cassini Division, which had once been thought to be empty.

Gaps in Saturn's rings have long been attributed to the gravitational influence of the planet's moons. Any particles in the Cassini Division, for example, would orbit Saturn exactly twice as fast as the moon Mimas, which is more distant from the planet. Thus, like a child being pushed on a swing, they would get a gravitational nudge from that large moon every other orbit, which would eventually kick them into another part of the ring. But as the ring features grew larger and multiplied on the TV screens, it became clear that such "orbital resonances" could not explain everything. One suggestion was that each groove in the rings might correspond to the orbit of a large moonlet sweeping its own path clear. Said Smith, "The mystery of the rings keeps getting deeper and deeper until we begin to feel it's a bottomless pit."

As the days went on, the ring discoveries tested Smith's vocabulary of adjectives. An eccentric "out of round" ring was found lying like a lopsided snake beside one of the dark ringlets. Then high-resolution photos of the skinny F ring showed that it was really three irregular rings knotted and "braided." "F-ring particles," said the astonished Smith, "do not appear to be following the classical laws of orbital mechanics as we know them." He added, "They're obviously doing the right thing; we

just don't know what the laws are."

Moons have other ways of causing trouble—or order. Some moons, it seems, are the sheep dogs of the sky. While studying photographs taken by the spacecraft in October, Voyager scientists Andy Collins and Dave Carlson discovered two previously unknown moons, Saturn's 13th and 14th, traveling just inside and outside the F ring. Borrowing a theory advanced by astrophysicists Peter Goldreich and Scott Tremaine to explain the rings of Uranus, Smith and his colleagues speculated that the moons' gravitational forces act to "focus" the ring particles, keeping them in the narrow, 50-mile-wide ring. The outer moon, they explained, moves more slowly than the ring particles and so tends to drag them back, slowing them down and causing them to drop into a lower, tighter orbit. On the other hand, the inner moon is faster than the ring particles and tends to pull them ahead, boosting their energy and kicking them into a higher orbit. The result is that particles cannot leak either up or down. "It's a subtle process," admitted one exasperated Voyager scientist, as he tried to explain it at a press briefing.

Another moon, only 50 miles in diameter, Saturn's 15th, was discovered by Voyager circling just outside the sharp edge of Saturn's A ring. It, too, may serve as a shepherd's role (one suggested naming it Lassie). "It's entirely possible," said Smith, "that this little satellite is bounding and controlling a ring hundreds of thousands of kilometers across." Could another, as yet undiscovered moon be patrolling the inside edge of Saturn's C ring? Said Smith, "We ought to bet on it right now."

Perhaps the most baffling phenomena that Voyager 1 and its human masters encountered were the "spokes"—dark radial fingers in the B ring that appeared to be rotating around in the direction of orbital motion. They were first sighted in early October, and a

planned movie sequence of Saturnian cloud motions was quickly diverted to filming the spoke motion. Because particles in different parts of the rings revolve at different speeds, such features should have been torn apart as soon as they formed, but the movie showed individual spokes lasting a few hours. "The spokes," complained Smith, "are giving us nightmares."

By encounter's end, the ring theorists were sleeping easier, if not longer. In views from the other side of Saturn, looking back across the rings, the spokes appeared as bright streaks instead of dark, suggesting that they were composed of very fine particles, presumably ice crystals, which tend to scatter light forward more efficiently than backward. A special movie made by JPL computer-graphics wizard James Blinn revealed that the spokes were rotating in step with Saturn's magnetic field. That led JPL physicist Richard Terrile to theorize that the small ice crystals get electrically charged by collisions in the dense ring, levitate above it, and line up like iron filings in the magnetic field. According to project scientist Stone, electrical and magnetic effects could also be responsible for the weird behavior of the braided F ring, which is also composed of very fine particles.

Competing with the rings for space in Saturn's sky (and for the attention of astrophysicists at JPL) are the 15 known moons of Saturn. Voyager 1 gave astronomers their first clear look at these satellites, most of which have ancient surfaces that bear the scars of four and a half billion years of fighting the traffic around the Saturn system.

Mimas, which Voyager scientists nicknamed "the death star" for its resemblance to the battleship in *Star Wars*, is dominated by a huge deep crater that is more than a quarter of the moon's 220-mile diameter across. True, ring what seem like cracks from the crater around to the moon's back side, geologists speculated that Mimas was nearly broken apart by the impact that caused the crater.

Saturn's 10th and 11th moons, one of which may have been detected by Earth-based astronomers as early as 1966, could be the remnants of a moon that did not survive its trial by impact. The orbits of the two moons are only 30 miles apart; Voyager's photographs show them like chipped teeth floating in front of Saturn's yellow disc.

Reheia, one of Saturn's larger moons, named for Zeus's mother, was inspected at close range and found to have the most ancient battered surface of all. "Shoulder-to-shoulder craters," remarked planetary geologist Larry Soderblom. For contrast, there was the back side of Dione, faced with wispy white streaks that came together at a suspicious-looking crater. Had Dione been cracked as well? The scientists thought so, and speculated that the bright wisps were water leaking through cracks from the moon's interior and then freezing.

One exception to the battered moon syndrome was Enceladus, which appeared to be perfectly smooth and uncratered. A theory advanced in Pasadena was that the combined gravitational forces of Dione, which orbits near by, and Saturn pull and stretch Enceladus, heating its interior and softening its surface. Astronomers have suggested that matter blown or spewed off Enceladus could be the source of the mysterious E ring. Voyager 2 will take a closer look at Enceladus, as it will at another mysterious moon, Iapetus (home of the Star Gate in 2001), which is five or six times as bright on one side as it is on the other.

Most of Saturn's moons range from 50 to 1,000 miles in diameter. According to an early analysis by geologist Eugene Shoemaker, they are composed mostly of ice, contain some rock, and probably resemble the nuclei of comets. Then there was the veiled lady, Titan. Astronomers could not help wondering what might be lying, or crawling, under its frustrating cloud cover. Some 3,000 miles in diameter, Titan is nearly as large as the planet Mercury and is the